Contract NASW-2837 &
Contract NAS8-32229

DOE/NASA SIMS PROTOTYPE SOLAR SYSTEM #4

PART 1 MARKET ANALYSIS

PART 2 MODULAR MANUFACTURING COST ESTIMATE

Prepared for:

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Reply to Attn of: BC01

FEB 13 1980

TO: NASA Headquarters
Attn: LB-4/Nathaniel B. Cohen

FROM: BC01/Richard J. Allen

SUBJECT: Coordination of Economic Analyses

As requested in Dr. Frosch's letter of July 9, 1979, enclosed is an economic analysis study (DOE/NASA SIMS Prototype Solar System #4) performed for this Center.

The study should be assigned to Primary Category 2C3, Secondary Category 2C2, on the list of NASA Economic Studies.

Richard J. Allen

Richard J. Allen
Center Comptroller

Enclosure

1. Introduction, Background, and Patent Status.

1.1 Introduction

This report documents the findings of the IIT Research Institute (IITRI) market study of the "SIMS Prototype System 4", a solar heating and domestic hot water (DHW) system. This system was developed under the management of NASA Marshall Space Flight Center by IBM, Federal Systems Division, for the Department of Energy, as part of a Solar Heating and Cooling Systems Development Program. The objective in developing this particular system is to demonstrate the feasibility of prepackaging currently available solar heating components into modular sub-systems for site assembly. The project resulted in a documented design and installation procedure and a performance test report.

This IITRI study profiles the potential markets and applications for this particular system in the non-federal market by assessing the needs and requirements of potential users and specifiers, by characterizing the nature of the market and the competitive environment, by identifying the barriers to commercial acceptance, and by estimating the size of the potential market. This analysis will provide a perspective for making conclusions and recommendations regarding the commercial potential of SIMS Prototype System 4.

1.2 Background

Solar technology as an alternative energy source has clearly experienced an intensified level of interest and commitment within the public and private sector. Solar heating and cooling (SHAC) as one component of the solar solution, has served as a leading indicator of the problems and opportunities inherent in accelerating the commercialization and market development of alternative energy products and systems. The Solar Heating and Cooling Demonstration Act of 1974 has provided the formal basis for this initial market thrust by SHAC systems.

Rising fuel costs offer an increasing justification for considering solar systems for residential, industrial, and agricultural markets. At the same time solar hardware has become more reliable and maintainable, and more readily integrated with conventional heating, ventilating, and air conditioning (HVAC) products and methods of distribution. This has contributed toward an improved image for solar systems among users and specifiers. New tax incentive legislation (e.g., 50% for residential, 30% for business) continues to reduce the economic barriers as well.

It is also evident that solar heating and cooling is still at the early adopter stage of market development, where the penetration of total possible capture potential is still below 2%. A characteristic of this stage is that technical novelty often outweighs rational market considerations concerning economics and energy conservation. As the forces described in the previous paragraph become more pronounced the market can be expected to mature and expand accordingly within the next decade. Penetration of the core of market demand will require a greater emphasis on cost reduction, reliability, and serviceability.

This background information indicates in a general sense the state of the market for solar heating and cooling systems. These issues will be expanded upon in the following sections of this report, with a particular emphasis on the potential of the SIMS Prototype System 4.

The solar heating and domestic hot water system that this study focuses on is an air-type solar energy collection configuration. It consists of a solar design which has been prepackaged into modular sub-systems as much as possible, and subsequently assembled at the site and monitored for performance. The system consists of commercially available solar components, including Solaron solar collectors, a rock storage bed, air handling equipment, heat exchanger, DHW preheat tank, piping, controls, etc.

The system was designed to be installed adjacent to a small single family residence; and was installed for demonstration purposes adjacent to a mobile home at the Mississippi Power and Light Company Training Facilities, Clinton, Mississippi. The system is designed to handle a load of 60 million BTU, with 240 ft^2 of collector supplemented by an 80,000 BTU gas heater. It is estimated by NASA/IBM that the installed system cost is about $8,050 (about $33/$ft^2$ of installed collector area) for a production volume of 100 units.

It is important to distinguish between what the IBM custom-designed system represents in terms of economics and performance, and what the system has the potential of offering thru refinements in the hardware and design configuration. The overall goal is to assemble a system package which will most effectively serve the needs of its potential market segments. This requires attention to simplicity, reliability, serviceability, aesthetics, economics, etc. By making assumptions and qualifications concerning the optimization of these product features a realistic assessment can be made of the conceivable depth and breadth of application of the concept represented by SIMS Prototype System 4.

1.3 Patent Status

The SIMS Prototype System 4 utilized commercially available components and products. The collector system in particular is patented by Solaron, Denver, Colorado (U.S. Patent No. 4,073,283). It does not appear that system design techniques, packaging, hardware, and instumentation applied by IBM offer any patent potential.

2. Technical Issues

The SIMS Prototype System 4 represents an approach to the application engineering, packaging, and installation of an air-type solar heating and domestic hot water system. As has been described, this system is an assembly of commercially available components which are prepackaged as mush as possible in the factory for simplified site installation. The system has been designed initially for location adjacent to a single family dwelling. The schematic on the following page illustrates the type of system which has been assembled by IBM under the direction of NASA Marshall Space Flight Center.

The nature of the configuration and the performance record are important factors in defining a solar system's market potential. As a result we requested the Solar Energy Research Institute (SERI), Market Development Branch, to review the design and performance packages with the purpose of providing a technical perspective on the SIMS System 4 in relation to other systems and in relation to accepted industry practice. This provided a base of information from which we could attempt to position the system in the current and expected future solar heating and domestic hot water marketplace.

The SIMS System 4 is a first class, 'cadillac', system primarily as evidenced by the use of Solaron collectors. Solaron is a well respected company with a proven record of accomplishment in the fledgling solar heating industry. Solaron has installed over 1,000 systems (representing more that 375,000 square feet of collector area installed over three years), an indication that the design and performance are well proven and are suitable for widespread residential, industrial and agricultural applications. Dr. George Löf, President of Solaron, is noted for his contributions over 20 years to the development of solar technology as a credible energy alternative.

The SIMS Sytem 4 utilizes a good design and appears to perform well. Utilizing standard components and systems, the design is fairly straightforward. The concept of prepackaging the system as much as possible, offers the potential of reducing field

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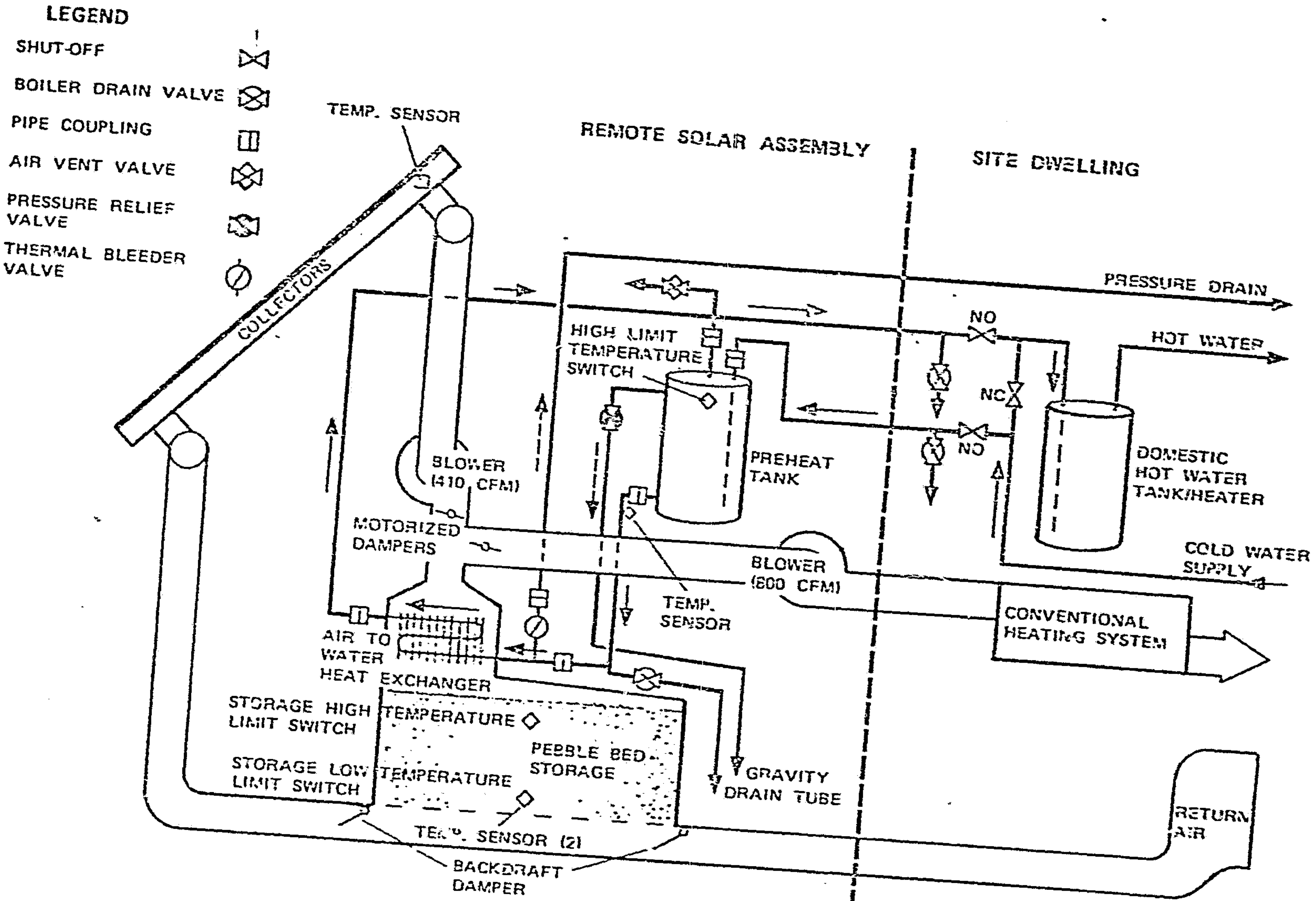

Figure 1. "SIMS System 4 Diagram - System Design Package for SIMS Prototype System 4, Solar Heating and Domestic Hot Water", DOE/NASA CR-150839

installation problems and cost. This has particular value for retrofit applications (as opposed to new construction), where the design, assembly, and installation of the solar system proceed fairly independently of any structural modifications to the building. More detailed implications for the market development potential of this 'prepackaged', stand-alone system will be presented in the following sections of this report.

Specifically as a result of their review of the SIMS System 4, SERI has made the following comments for consideration in optimizing the design and performance of the system:

- An 80 gallon perheat tank is generally more preferable than a 52 gallon tank.
- Back draft dampers have a tendency to leak and therefore may not present the best tradeoff between performance and reliability.
- The control system appears to be almost too responsive, sensitive, for typical applications.
- The dynamic pressure could be monitored just as readily by a pitot tube, instead of a more expensive wind tunnel-type gauge.
- The flow rate could be improved by installing a pump and reducing the 1" diameter pipe to ½", and thereby increasing flow rate from 0.52 gal/min to 1 or 1½ gal/min.
- The high temperature differential of 25°C from collector to load could be reduced to 10°C.
- There should be a bypass of the rock bed storage during the summer in order to reduce parasitic power consumption when only DHW is needed.
- The rock bed should be higher than it is wide in order to promote proper flow, reduce dead space, and assure that sensors are providing reliable data.

The Appendix A provides an indication of other factors which should be considered in practical application of solar technology; and Appendix B indicates the range of building code issues which are invloved.

While economic incentives are certainly alleviating some of the barriers to serious consideration of solar by the mass market, it is clear that cost control and reduction should remain a primary

objective of any system design approach. The pricing of the collectors, blowers, controls, etc. is determined by the suppliers, with some reductions possible by means of volume purchase agreements. The remainder of the system, however, provides an opportunity for the systems designers to assure that the design is cost effective. Selection of materials and hardward for supporting the collectors and for packaging various of the components could represent a significant opportunity for controlling the installed system cost. It is also conceivable that alternative commercially available collectors and systems components may offer cost advantages. But it is important to consider the quality and performance of such alternatives as well. In any case a competitive bidding situation for a large volume production order may provide additional reductions in total installed system cost beyond the $8,050 for 100 units as estimated by NASA/IBM.

3. Competitive Environment

The gross long term potential of the SIMS System 4 is a strong function of the competitive technologies which will capture market share from air-type solar heating and domestic hot water systems in distributed applications. Many of these technologies are still at an early stage of market awareness and development themselves. Thus, there is uncertainty concerning the long term contribution each will make to the energy marketplace. The competitive approaches to the SIMS System 4 are listed below:

- o Improvements in traditional gas, oil, and electric heating and hot water systems: burner design, flue gas recirculation.
- o Traditional conservation techniques: insulation, thermostat set back, storm windows, etc.
- o Passive solar techniques: trombe wall, greenhouse, direct gain, insulating shades, etc.
- o Liquid-type solar heating and domestic hot water systems.
- o Other air-type systems and configurations.

Each approach has a unique set of market advantages and limitations, which in turn define a unique set of appropriate markets and applications. Market advantages and limitations are based on such factors as economics, aesthetics, simplicity, established channels of distribution, state of diffusion in the market, etc. Appropriate market segments include such areas as residential, light industrial, agricultural, etc. These two aspects of each competitive approach (i.e., the advantages and limitations, and the appropriate market segments) define the relative impact which each will have on the potential of the SIMS System 4 in its appropriate markets and applications.

It is also clear that the relative advantages and limitations of each competitive approach will change over time. Technical improvements will be made, demand and volume will increase, and experience will define the market and application 'niches' which are most successful and appropriate for each approach. Thus our analysis should be viewed with these qualifications in mind.

There are several implications which the competitive environment has on the potential of the SIMS System 4. Most experts agree that before even considering an active system the decision makers in a rational market (i.e., a market which is not at the early adopter/innovator stage) should implement as many conservation and passive techniques as is justifiable. The return on investment in conservation and passive techniques is much quicker and can indeed have a significant percent contribution to total energy conservation. This applies to both new and retrofit construction.

The decision maker in a rational market will choose to minimize his expenditures by first implementing those techniques which will have the greatest impact on his energy consumption at the lowest cost. This includes consideration of first cost, maintenance cost, replacement cost, and takes into account government incentives and supports, technical complexity, supplier reputation, level of energy conservation, geographical locations, etc. Generally it is not prudent to invest in an active system when the absence of conservation and passive techniques precludes the use of the active system at its best possible level of efficiency. This issue is particularly relevent in today's inflationary economy, where borrowing is expensive and the majority of individuals have neither the savings nor the discretionary income to even seriously consider an active system for retrofit with a cost in excess of $5,000.

The SIMS System 4 concept is represented as a fixed product line with a specified number of collectors, hence capacity, associated with each product (e.g., 135 ft^2, 203 ft^2, 271 ft^2, etc.). These relatively few available capacities will compete with custom design capabilities offered by such firms as Solaron, which are based on a more flexible responsiveness to individual load requirements and site conditions. It is true that the SIMS System 4 approach is analogous to current HVAC practice of offering a set of furnaces/boilers with fixed capacities, not infinitely

variable or custom in nature. But it is conceivable that taking this same approach with solar collectors does not really "buy" anything in terms of economies of scale for material or components. The collectors themselves currently account for about one-half of the total installed system cost. Therefore, custom sizing of the number of collectors for each application will more significantly impact the total cost than will the savings that accrue by minimizing the amount of custom design of the supporting hardware.

As mentioned above, the SIMS System 4 prepackaged approach will essentially compete directly with custom designed systems using standard components, as is done by Solaron and others today. The Appendix C illustrates applications analogous to a stand-alone solar collector configuration located on the roof of small industrial firms or adjacent to grain drying facilities for agriculture. This demonstrates that, aside from the special consideration given to monitoring instrumentation and some degree of prepackaging, the SIMS System 4 configuration is common practice today, and is adjusted for each end use situation. Never-the-less the SIMS System 4 indicates the importance of implementing ideas which reduce the amount of field handling and field adjustment required of the installers, building contractors, etc.

It is not the purpose of this market study to critically evaluate the selection of the particular collectors, pumps, controls, etc. The important consideration is that the system appears to be first class in terms of components used. Conceivably a more cost-driven component selection (with careful consideration to the impact which cost reduction has on performance, serviceability, life, etc.) could reduce installed system cost further. Even so, it appears that the installed system cost, for large volume production, would not be outside the range of \$5,000 to \$10,000 for a 240 square feet of collector, or about $\$20/ft^2$ to $\$40/ft^2$. This presents a serious problem for the retrofit market, particularly residential, where capital investment of this nature

is generally only done out of necessity by the majority of individuals (i.e., a water heater corrodes, a furnace fails, etc.) The commercial retrofit market is not as sensitive to such costs, due to the greater savings which could be realized, the more ready availability of financing, and the greater acceptance of life-cycle costing. Indeed, the commercial retrofit market is where such remote or roof-mounted configurations are being applied successfully by the solar industry today.

4. Barriers to Market Acceptance and Commercialization

Previous paragraphs have touched on several of the factors which represent barriers to acceptance and widespread commercialization of the SIMS System 4, while others are characteristic of active solar systems in general. In any case careful recognition of these issues provides a basis for estimating the relative opportunities in various market segments and their order of magnitude.

General Barriers for Active Solar Systems

The barriers to acceptance can be conveniently identified as either user-based or institutional-based These barriers are a strong function of the nature of the end-use market, whether residential or commercial. (In this sense 'commercial' is taken to represent all non-residential construction, generally requiring a higher degree of involvement of architects, engineers, etc.) The barriers to acceptance in residential construction are primarily due to the reluctance of suppliers and users in the residential market to innovate. Typically new construction practices and technologies are introduced at the commercial scale, where their selection, implementation, and performance can be controlled and monitored more effectively, where the risk is distributed over a larger volume of business, and where the potential benefits and return (e.g., savings) are greater. Residential building practice is based to a greater extent on thousands of small local contractors who often have cash flow problems, schedule and labor limitations, and are generally more risk averse than larger commercial planners, developers, and contractors. It is also evident that the residential construction industry is more comfortable with low technology than high technology, due to the relative ease of installation, and tolerance of error and misapplication which low tehcnology typically provides. Thus, it appears that while the total number of residential units in place and projected as new construction is large, the barriers to diffusion of the technology will in practice substantially control the penetration of this market segment by active solar systems. The commercial market, on the other hand,

is more readily motivated to implement solar technologies if the economics justify it and there is sufficient awareness about the availability of reliable equipment and its performance.

The most significant barriers to solar heating and DHW commercialization are listed as follows:

User-based Barriers

- Education and awareness about solar as an option
- Economics
  - First cost (e.g. for residential less than $4,000 is the most acceptable, greater than $8,000 is nearly unacceptable, particularly for retrofit)
  - Life cycle cost (e.g. 5-7 year maximum payback is most desireable for residential due to 5-7 year average stay in one residence)
  - Property taxes
  - Insurance cost
  - Financing cost
- Aesthetics
  - Deviation from tradition
  - Conflict with community standards
- Performance
  - Climate-specific installations
  - Availability of replacement parts and services
  - Simplicity
  - Serviceability
  - Life (e.g. 20 years minimum)
  - Noise

Institutional-Based Barriers

- Regional nature of building industry markets inhibits volume cost efficiencies and rapid diffusion of solar experience throughout the country,
- Building industry actors (architects, engineers, contractors, specifiers, unions) currently lack sufficient confidence in solar as an

option of 'everyday' consideration due to:

- Need for climate and application-specific performance data
- Need for climate and application-specific installation data
- Need for clarification of building codes with respect to solar at the local level
- Need for reassessment of building systems design procedures to optimize the value of solar
- Need for clarification of role of various trade unions in installing solar systems in terms of liability, warranty, etc.
- Need for education in the schools of architecture, etc. for long term penetration by solar.

- Concerns over utility rate structure and solar-based electricity demand fluctuations need to be resolved as solar systems gain acceptance in the mass market
- Channels of local distribution, and assured regional supply of systems and replacement parts and services, need to be further established for solar to achieve significant levels of specification and use
- Financing institutions must be more educated and aware of the impact of solar on resale value, and must be able to judge the relative reliability of systems and soundness of design

Appendix D provides an indication of the legal implications in developing a workable marketing infrastructure for solar systems.

Barriers Specific to the SIMS System 4

The acceptance of the SIMS System 4 concept is a function of the specific end-use market segments which it has the potential of serving. This is addressed in greater detail in the following section. In general the SIMS System 4 may be too expensive for the mass residential retrofit market if total installed system cost is not kept below $5,000. It does not appear that the SIMS System 4 could be cost competitive in the

new construction residential market due to inefficiencies in remotely locating the collectors, et. al. In terms of large non-residential buildings, the cost of solar installations should be no greater than 15% of the total building cost.

The concept underlying the SIMS System 4 is in some respects so indistinguishable from current practice in appropriate applications that it is not possible to focus on specific barriers beyond the general barriers identified above, as well as the technical and competitive issues raised in previous sections. What is useful, however, is to define the potential market segments which the concept is suited for in order to understand the role SIMS System 4 could play in the solar heating and DHW market place.

5. Markets and Applications

The principal markets and applications for the SIMS System 4 are viewed in the context of the demand for all solar heating and domestic hot water systems. General studies have been conducted over the last five years to identify, segment, and quantify the potential markets for solar heating and cooling and domestic hot water systems. Many of these studies have been done for DOE and its predecessors, the National Science Foundation, etc. It is not our intention to update these reports, but rather to utilize the best available data and informed opinion to formulate a market perspective for the SIMS System 4 in particular.

The SIMS System 4 must be viewed with respect to current practice in the solar heating and domestic hot water industry. In this context, it represents a typical application of available hardware which a knowledgeable combination of architect/equipment supplier/contractor/installer should be expected to be able to achieve in their normal course of business. This has several implications. First, it is clear that the solar industry is at a stage where there are insufficient numbers of knowledgeable and experienced individuals all along the design/distribution/installation chain. At least there are insufficient numbers at this point to support a substantial market demand. This will change over time as experience increases and diffusion of the technology is accomplished at all levels of an emerging marketing infrastructure. A second issue is that the SIMS System 4 does not offer any new advancement in the basic technology of solar heating and domestic hot water, beyond that which an applications engineer, given the same problem, would address. (We are discounting the peripheral monitoring electronics, which is not considered a part of the commercial system.) Thus the NASA/IBM effort for DOE may provide useful background data for those in the building industry interested in applying solar, but unknowledgeable or inexperienced in doing so.

Given this perspective, it is our purpose to evaluate the

market potential of the concept of a system which is pre-packaged and modular in nature for assembly adjacent to a building. We have segmented the market and evaluated each segment based on our perceptions of the viability of the SIMS System 4 concept. This provides a basis for subsequently quantifying the potential unit sales as discussed in the following section of this report. Each summary assessment is based on a variety of complex issues and considerations as detailed below.

The Residential Market

The residential market does not offer significant opportunity for the SIMS System 4 concept for either new construction or retrofit applications. It is clear that economics and aesthetics drive the demand for solar residential applications, aside from performance issues. In new construction it is both more economical and more aesthetically acceptable to integrate solar into the residence at the design stage. This includes consideration of the entire building structure as a conservation tool, with all of the implications for selection of insulating materials, air flow, direct gain sunlight utilization, and other passive techniques.

This sets the stage for consideration of active solar systems after every conservation effort has been made to assure that the solar active system can operate at the highest possible efficiency. Hydronic solar systems, while generally more efficient than air-type, are still more expensive and more complex. In fact the complexity and the potential for damage to residence interiors through leaking fluids both combine to limit the suitability of liquid-type, at least at the present time to commercial applications. As system reliability and installation techniques improve, liquid-type systems will become a more viable option in new residential construction.

It is also important to note that it is generally preferable, if at all possible, to hide the mechanical support systems of a residence within the structure itself. This is very readily

accomplished in new construction. Thus we do not expect any market demand for this concept for new residential construction, with the possible exception of multi-family dwellings. But even in this area it is much more likely that an active solar system would be integrated into the structure at the design stage.

The retrofit residential applications ,offer a somewhat more optimistic outlook for the SIMS System 4 concept. In existing residential construction, there is often little that can be done to easily integrate an active solar system. Consideration has to be given to the strength of the roof to support collectors, the availability of space to locate the thermal storage and pumps, and the suitability of the in-place heating system as a complement to the solar system. Thus it may be more straight forward and in some cases more economical to package a system as much as possible and locate it adjacent to the residence, in spite of the space consumed and the appearance. This assumes that there is sufficient access to sunlight to permit consideration of active solar systems in the first place, either on the roof or adjacent to the residence.

Again, most industry experts recommend that serious consideration be given to implementing conservation and passive solar techniques in existing residences prior to thinking about investment in an active solar system. There are two basic reasons. First, a significant percent reduction in energy consumed can be achieved through relatively inexpensive and uncomplicated conservation and/or passive means. Second, to reduce the payback period for an active system to its minimum it is necessary to assume that the structure is as energy 'tight' as is practicable. This perspective applies to rational purchase decision-making regarding active solar. It is not applicable to the early adopters in the market who are typically at the higher income levels. They do not generally base their purchase decisions on dollar savings, but rather on technical novelty or the 'cause' of conserving energy.

A distinction in market potential must be drawn between space

heating and domestic hot water (DHW). DHW applications of solar technology have been successful for several years, particularly in the warmer climates where there are no significant space heating needs. DHW solar systems are relatively easy to install and are fairly inexpensive, since only about 50 ft^2 of collector is typically required (depending on the climate), with minimum modification and addition to the in-place system. Since the SIMS System 4 is strongly tied to the application of space heating as well as DHW it is to be expected that its market penetration will lag that of the DHW-only solar systems.

Perhaps the most crucial aspect in considering the SIMS System 4 concept for the retrofit residential market is the installed system cost. This market segment is extremely sensitive to price. Considering the average family today, it is not likely that the cash is available for a purchase which might be considered superfluous, even at today's oil prices. For this reason an installed system cost in excess of $5,000 would be prohibitive and severely limit the market potential for retrofit applications, which in fact are the most logical market segments for this concept. Tax incentives and supports, while certainly useful and necessary, still may not be sufficient to persuade individuals to invest in solar active systems, unless they are extremely readily available, reliable, and have been proven to save 'x' dollars per year in the climate of concern to each individual. Again due to the cost involved, multi-family retrofit also does not offer a significant opportunity for the concept of solar heating and DHW. With this overall understanding of the retrofit residential market, we estimate the gross capture potential of the concept represented by the SIMS System 4 to be nearly insignificant when compared to custom designed active systems for new construction.

The Commercial Market

The commercial market segments represent varying potential for the SIMS System 4 concept, depending on whether the construction application is new or retrofit. The types of commercial

market segments which exist primarily include services (banks, franchises), institutions (schools, hospitals), light manufacturing (warehouses, small plants), and agriculture (heating of animal shelters, drying of crops). It is evident that the negative aspects which were described for new residential construction are not as pronounced when considering new commercial construction. Architects, designers, contractors, etc. are significantly more receptive to new and innovative technologies, if they offer the potential of improving or simplifying building system performance.

Of course economics still dominates the decision-making process, and aesthetic concerns can be just as important depending on the particular firm or organization involved. It is still true in general that new commercial construction would tend to integrate the solar system at the design stage so that the collectors are roof-mounted (thus conserving real estate), and the associated pumps, storage, etc. are within the boiler room. Again, the economic and aesthetic benefits in integrating active solar systems at the building design stage almost preclude the potential of the SIMS System 4 concept for new construction, particularly when the structure must reflect the image of the firm (e.g. banks, franchises, etc.) Refer to Appendix E for a discussion of the important issues which should be considered in 'designing in' energy conservation in institutional and industrial buildings.

Retrofit commercial applications offer the most suitable market framework for the SIMS System 4 concept. This applies to sites which have solar access and real estate or roof suitable for location of the collectors and storage, as well as a reasonable level of insulation to bring payback periods within the range of common practice for other heating systems. Some market segments such as services (banks, franchises, etc.) and institutions (universities, hospitals, etc.) may have problems in finding suitable and aesthetically acceptable sites; but for other segments such as light manufacturing and agriculture these issues should not pose significant barriers to consideration of the concept. Of course climatological and performance factors

remain important, as does the potential of the concept for economically interfacing to the existing power plant.

One important factor in considering the SIMS System 4 for the retrofit commercial market segments is that the concept of remotely situating the collectors and storage as an add-on to the in-place structure is the concept applied today for such situations. This is illustrated by the Solaron literature presented in the Appendix C which shows a roof mounted collector scheme for a light industrial application and a remote collector scheme for agricultural use. It is not clear that the SIMS System 4 in particular offers a significant technical or economic difference vis-a-vis currently applied methods. In fact, some of the support hardware (e.g., aluminum support channels, braces, etc.) appear to be over-designed. This makes it unsuitable as a high volume, cost-effective sample for unknowledgeable contractors, designers, etc., to follow in practice without significant modification and re-design.

The principle which the SIMS System 4 does effectively demonstrate, and which should be seriously considered by solar systems manufacturers and suppliers, is the concept of pre-assembling as much as possible the sub-systems so as to minimize field installation efforts. This approach may not significantly reduce total installed cost, but at this early stage of market development it may encourage contractors and designers to try to implement solar systems in retrofit applications. This pre-packaged 'kit' must be straightforward in concept, simple to transport and install, and reliable in performance.

The agricultural market segment is somewhat unique in that the end-use of the heating may be for other than human comfort, that is, for process use. Drying of grain, soybeans, etc., as well as heating chicken houses, farrowing houses, etc., are typical uses to which solar techniques are being applied. The Appendixes F and G illustrate solar passive techniques successfully applied to agriculture. The U.S. Department of Agriculture

(USDA) and its Extension Service Programs at various universities have efforts directed at such applications. In fact the USDA has announced the availability in January 1980 of a portable kit for providing solar heating for the above types of applications. The cost of the materials is expected to be about $2,500. Refer to the Appendix H for a copy of the news release describing this development. The low cost of this system combined with its portability could represent a significant deterent to consideration of the SIMS System 4 for agricultural use, if both approaches offer comparable benefits in terms of efficiency, simplicity, etc. It is important to clarify these issues prior to further consideration of the SIMS System 4, or a revised design, for agricultural applications.

Overall, the commercial sector offers greater potential for the SIMS System 4 concept, particularly for retrofit use in light industry and agriculture. These markets will in any case develop slowly due to the innovative nature of the technology and the still infant stage of development of a viable marketing infrastructure. Once these barriers are overcome the market will be at a stage which more appropriately permits the serious consideration of active solar systems as an alternative to continued increases in fuel cost and uncertainties in fuel supply. It does appear, however, that the overwhelming opportunity for active solar systems lies in the new construction market (either residential or commercial). The barriers to installing solar heating and DHW systems in retrofit applications are expected to continue to severely restrict the potential of active systems for retrofit use without a major breakthrough in economics and technical simplicity. The following section consolidates all of these observations into an estimate of the overall potential which the SIMS System 4 concept represents.

6. Market Size

There are two important parameters to consider in quantifying the market potential for the SIMS System 4 concept. One is the total capture potential which the system represents; and the other is the expected penetration of this potential as a function of time. The time frame we have assumed for purposes of this analysis is from 1980 - 2000. This time period is important for solar because it is not a steady state environment (as might be expected after the year 2000), but is rather characterized by a dynamic growth in annual demand (hence, penetration) as the market develops and matures.

The previous section has defined the market segments we expect to offer the most viable opportunities for the SIMS System 4 concept. These market segments consist of the commercial retrofit market in light industrial and agricultrual applications. The other segments, while perhaps offering some opportunity for sales, do not represent a basis for making a confident estimate of potential, or for committing resources to a market development program. Thus our market size and penetration estimates are limited to light industrial and agricultural applications.

The light industrial retrofit market between 1980 and 2000 is drawn from (1)buildings already in place, and (2) buildings yet to be constructed which will not have solar active systems integrated at the design stage. Buildings that are already in-place do not have a high potential for solar retrofit. The primary rationale is that these buildings are not as energy efficient as newer construction, and therefore require an additional substantial investment to improve the overall insulation performance of the building and the performance of the auxiliary heating plant. It is also true that the owner must be committed to upgrading his facility in general. He is less likely to consider investing in a new heating system, which he

may not be able to realize a financial benefit from for several years, when his building may not last very much longer or have significant resale value. Thus we expect the primary potential for light industrial retrofit to be realized from buildings yet to be constructed between 1980 and 2000 (and beyond), in particular those which have not incorporated active solar systems at the design stage.

There are in excess of 3000 new industrial construction projects annually in the United States. Assuming a fairly stable level of construction, there will have been put in place between 1980 and 2000 a total of 60,000 industrial buildings. As many as two-thirds of this total, or about 40,000 units, may be found acceptable candidates for active solar system consideration. Of these 40,000 units about 15 percent or 6000 units may actually incorporate active solar systems at the design stage. The remaining 34,000 units represent the capture potential between 1980 and 2000 for retrofit active solar applications.

Of the 34,000 potential units, it is likely that the total maximum achievable penetration, over the period 1980 - 2000, will be on the order of 10 percent or 3400 units. This is due to the early growth stage of the technology and all of the inherent complexities in overcoming traditional practice and creating a market inertia in favor of solar technology. Thus, the average annual penetration over this 20 year period is 170 units, skewed heavily toward the period 1990 - 2000. (Sales in the early 80's may be on the order of 20 - 30 units/year for industrial retrofit installations.

The agricultural retrofit market is based on the inventory of farms in operation. As of 1974 there were an estimated 1.7 million farms in the United States with annual sales of $2,500 or more, representing about two-thirds of the total number of farms. Of the 1.7 million about one-third, or 550,000, have income greater than $20,000/year. This income bracket would most likely provide the major initial market between 1980 and

2000 for solar systems. Applications would range from grain drying to heating for animal shelters, etc. Much depends on the price and simplicity of a system for this market segment. In this area the SIMS System 4 may find significant competition from much simpler and less expensive approaches based primarily on passive collection and storage techniques which feed in to the existing system. Of the 550,000 it appears that about 40 percent or 220,000 might be most suitably located to benefit from use of the sun, and thereby offer the greatest initial potential for justification of solar energy techniques.

Penetration of the 220,000 farms, comprising the capture potential for 1980 - 2000, is difficult to judge due to the divergent results obtained when an inexpensive approach is used vs. when a more expensive approach is used. If farm process heat can effectively be provided through use of a $2,500 solar materials kit (as offered through the USDA) vs. a system based on the SIMS System 4 concept, then the market for the latter will be very small. If the SIMS System 4 could be comparably priced based on the performance required, then its penetration will be substantially greater. Penetration could represent a range between 1 percent and 10 percent (2200 vs. 22,000) or greater over the 20 year period 1980 to 2000. This translates to a penetration of about 110 units/year vs. 1100 units per year average. The uncertainty in the range of this estimate indicates the need for a more focused assessment to define the specific product requirements of the agricultrual market and the market size and penetration this represents.

The light industrial and agricultural segments could be expected to represent about 80 percent of the total market. This indicates a total capture potential of 275,000 units. Of this total potential between 1980 - 2000, the total penetration could be expected to range from 7000 units to 31,000, depending on which agricultural penetration is found to be most realistic. This translates to a possible annual unit sales average of 350/year to 1550/year for the SIMS System 4 concept, or a modification thereof.

7. Summary, Conclusions and Recommendations

......The market for solar heating and domestic hot water systems will become increasingly viable over the next decade as fuel costs increase, system reliability and performance increases, and potential user segment familiarity with solar increases.

......The dominant market for active solar heating and domestic hot water systems is in new building construction, not in-place, or 'retrofit', construction.

......New construction is much more viable market than retrofit construction due to the inherently greater efficiencies and economics possible, and the more appealing aesthetics of an integrated solar design.

......The SIMS System 4 concept has its greatest potential for retrofit applications, particularly in the light commercial and agricultural segments, due to their lesser degree of concern about aesthetics, fewer site restrictions, and more natural inclination to buy on the basis of life-cycle costing (vs. low initial cost).

......The concept of the SIMS System 4 is somewhat unique in that it is prepackaged as much as possible, and positioned as a set of standard products of incremental capacity (e.g. 135 ft^2, 203 ft^2, 271 ft^2, etc. of collector area).

......The SIMS System 4 configuration itself and its assembly adjacent to a building is not unique, as this is a standard design approach taken by manufacturers, contractors, etc. faced with the similar circumstances of a retrofit, light commercial or agricultural application.

......The SIMS System 4, while representing a very good performance record, design, and selection of purchased hardware, could be made more cost-effective in terms of the supporting members for the collector, et al in order to reduce installed system cost.

......Most experts tend to discount the potential of active solar systems for the retrofit market due to the more prudent approach of implementing conservation and passive techniques, which provide a significant energy savings return on a rather small initial investment.

......Typical solar heating and DHW installed system costs range from $30 to $35 per square foot of collector area; but this is a strong function of storage requirements, propensity for interfacing with existing heating plant, and level of quality of collectors and pumps.

......The total capture potential of the SIMS System 4 concept is estimated to be 275,000 units between 1980 and 2000.

......Penetration of the capture potential between 1980 - 2000 could range from an average 350 units/year to as many as 1550 units/year, depending on the extent to which the concept is found to be compatible with the economic and performance requirements of the agricultural market.

......A follow-up study activity could be directed to clarify the extent to which the agricultural market represents an area of consideration for market development of the SIMS System 4.

......The greatest proportion of market penetration of the capture potential is skewed heavily toward the time frame 1990 - 2000, based on the identified barriers which are expected to inhibit rapid development of the market.

......Even with rising fuel costs and hence greated economic justification for considering the active system, it is clear that the natural process of market infrastructure development and user education and acceptance will realistically provide for a slow and gradual build-up in demand which will become significant in the late 1980's.

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APPENDIX A

PHYSICAL CONCERNS IN THE INSTALLATION OF SOLAR SYSTEMS

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ABSTRACT

The Ehrenkrantz Group (TEG) has been active in the national solar data program. The Ehrenkrantz Group, architects and planners (located in New York), has had extensive experience in solar design research and analysis, as subcontractors to PRC Energy Analysis Company in management support work for the Department of Energy. This paper is a product of our experience gained under this subcontract. TEG has performed over 100 design reviews for DOE during the last eighteen months. This has provided TEG with the opportunity to witness, firsthand, the types of physical problems solar designers have been confronting in the design of solar energy systems. TEG's experience has included both the review of contract documents and onsite inspection of these facilities, which have been sponsored by DOE National Solar Heating and Cooling Demonstration Program.

This paper articulates the physical (rather than mechanical or electrical) aspects involved in the design and installation of solar systems. It also addresses the typical physical factors and problems encountered in design. In addition, it comments upon the cost effectiveness of various approaches.

This paper discusses design characteristics of the collector and storage loops, using existing technology, and is unrelated to the specific application of the solar energy collected (i.e., the demand loop--whether domestic hot water (DHW), heating, or cooling--is not covered in this paper). Rather, it discusses TEG's specific experience relative to what solar designers nationwide are designing in the installation of solar collectors, array structures, piping and storage equipment, with particular emphasis on cost-effective alternatives.

Most importantly, TEG plans to share its experience in the state-of-the-art in solar systems to allow a greater utilization of a higher percentage of the energy everyone is trying so hard to collect.

COLLECTOR SELECTION

Secondary Collector Attributes

What are the factors that must be considered in order to select the "best" collector for a project? Obviously, the overall collector efficiency, based on the expected load profile, is of prime importance. However, once the total net collector area requirement has been defined, there are probably still 10 to 50 collectors available to fit these requirements.

Collector Size Affects Cost. What secondary collector attributes might affect your choice? If cost is important, the decision should rest on the lowest cost per Btu of an installed collector. The size and construction of different collectors can have considerable impact on their installed cost. For instance, collectors with larger areas usually cost less per square foot to install than smaller collectors because a greater net area is being installed with approximately the same amount of work. Depending on their location and support design, taller collectors tend to be cheaper to install because they require fewer vertical supports and, therefore, fewer roof penetrations into flat roofs and fewer footings for field-mounted installations.

Collector Size Affects Row Spacing. A good rule of thumb for determining the distance between the rows seems to be that the shade angle should not greatly exceed the angle of the sun on December 21 at 12:00 noon. The highest continous obstruction on the southern row shall not cast a shadow on the lower glass opening of the next row. This means that if exterior manifolds are used, the top of the manifold must be considered, not the top of the collector. Of economic interest is the fact that collectors with exterior manifolds tend to cost more to install than collectors with interior manifolds.

Pitched Roof Considerations. On a pitched roof, wider collectors tend to require less wood blocking and can, therefore, be more cost effective.

Details Affect Support Design. Collector attachment details can also have a cost impact. Some collectors require special structural connections, such as pipe or Unistrut. If these special connections cannot be made integral parts of the structural support, they constitute extra cost. This will detract from the cost effectiveness of the particular collector. Therefore, it is important to review the connection requirements for the collector prior to designing the structure. Careful design can maximize the collector's capabilities; e.g., careful design can accommodate requirements such as type or location of supports.

Differential Metals. Regardless of what type of collector and support you use, you must prevent differential metals from coming in contact with each other and causing deterioration due to galvanic action. Place non-metallic material between the different metals. Bitumastic materials, neopreune and teflon are examples of materials that have been used successfully.

Aesthetics. You should also consider the aesthetic implications of solar designs relative to scale, support design, and piping arrangement. Many designs we have reviewed did not include elevation drawings. The designers would receive a rather unpleasant surprise at the system's appearance if the system were built as designed.

Tracking Collector Considerations. If you are considering tracking collectors, be sure to review their past performance. These collectors do have substantially higher performance in direct sun, but they depend on motors and other moving parts; and if Murphy's Law can be relied on, these parts will cease to move at the wrong time. There are many tracking collector alternatives. Some collectors have tracking mirrors and stationary piping. Some have tracking piping and stationary mirrors. Still others have tracking piping and mirrors or focusing lenses. Whatever the makeup of the collector considered, remember that the two most common physical problems encountered are failure of the motors that drive the tracking mechanism and failure of the rotating pipe connection. In general, a system will be more dependable if you carefully scrutinize these two crucial areas and check with users regarding personal experience. In addition, review the "mirror" material for use in your particular area. Is there any air pollutant that would either deteriorate or coat the mirror material?

COLLECTOR MOUNTING LOCATIONS

In the designs we have reviewed, collectors have been mounted on either flat roofs, pitched roofs, or the ground. Each location has its own installation requirements, advantages, and disadvantages.

Flat Roofs

The most common collector location for the DOE Commercial Solar Demonstration projects has been on flat roofs. The following factors should be taken into account for this appproach to be the most reliable and cost effective.

Building Structure Affects Collector Supports. The distance between the vertical portions of the support structure attached to the roof will vary; the capacity of the structure to accommodate point loads will dictate actual support spacing. We have seen one design where the building structure could not accept point loads, so the collector support structures were designed with vertical legs of only four feet on center, requiring 700 pitch pockets. Another design spanned more than 50 feet across a whole roof. The most economical spans seem to be approximately 10 to 15 feet. The relative orientation of the collectors to the building structure and, of course, the type of building structure -- concrete, steel, or wood -- will have an effect on the collector support. If the collectors run at right angles to the secondary building structure, there is the possibility of locating the legs of the collector support structure at regular intervals. If, however, the collectors run parallel to the secondary members, the collector vertical supports must be located directly over a single secondary member. This will mean that the member will be required to support the total load, or that an additional structural frame will be provided above the roof to carry the collector supports. The designer may elect to have the collector support span across the whole roof. Thus, the structural orientation of the building has a major impact on the design and cost of the collector support structure.

Obviously, if the collectors can be aligned with the building structure, the collector support legs can be set in a regular fashion. If, however, the collectors are set at an angle to the building, the support legs may have to be located in an irregular pattern in order to conform to the roof structure.

Collector Weight. Some designers have been concerned with the dead load of the collectors. However, the collector weight is seldom a factor because the dead load of the collectors is really quite minor compared with the weight of the supports added to the wind loads, and most flat-plate collectors weigh about the same.

Array Spacing. The decision whether to array the collectors in rows one, two, or more collectors high should be based on spans, structural loads, roof area, obstructions, aesthetics, and pipe configurations. Distance between arrays is usually less than 10'-0" when the array is only one collector high, allowing piping to be supported off the collector supports. If collectors are spaced further apart than 10'-0", the piping will require special roof supports. In this case, the supports must be detailed. Even so, we have found it is usually more economical to install collectors at least two collectors high, especially if the collectors are not tall. This approach often has greater visual impact and minimizes piping and structure requirements.

Complex Vs Simple Structural Approach. We have observed that when ong span, triangular shaped structures are required, there is a common tendency to select aluminum or steel tubular space frames. This approach, although aesthetically pleasing, can be extremely costly and labor intensive. "Hairy" space frames tend to cost more and are hard to come by. They may have their place, but be sure to cost compare different alternatives, unless cost is no object.

Anchorage Details. Once you have selected a collector support structure, it has to be anchored to the building. There are many viable approaches. However anchorage is approached, the connection must be designed to support all the different loads which will be imposed on it, including dead loads, horizontal thermal movement, and live snow and wind loads. Failure of these anchoarge details will result in roof leaks, if not worse problems.

Pitch Pockets. Pitch pockets are one of the oldest and most common approaches. However, one must be careful to specify and install them carefully. If used for piping, do not install more than one pipe in each pocket or the differal movement may cause problems.

Sleeve and Canopy. The National Association of Roofing Contractors are very much down on the use of pitchpockets because of the maintenance requirements and much prefer the use of round column supports with pipe sleeves flashed into the roof and caulked around the top with a canopy to shed water straped and caulked to the support above the sleeve.

Field Fabricated Curbs. Curbs are also an old standby. If fabricated in the field, be sure to carefully detail and specify the construction and roof anchorage in order to withstand the horizontal as well as vertical loads that will be applied to it.

Prefabricated Curbs. Manufactured curbs must also be selected and

fastened to the roof to withstand future loads. If curbs are incorrectly installed, any movement that ensues could cause a roofing failure and leaks.

Neoprene Sleeve. If the vertical collector support is a regular shape, round or square, there are manufactured neoprene sleeve curbs that are available for use.

Sleeper. In some designs there have been attempts to minimize or eliminate roofing penetrations. Sleepers bolted to the roof have often been used, especially in retrofits. They can be effective, but be sure to protect the bolt penetrations of the roofing. Another problem is that if the insulation under the roof's waterproof membrane is not sufficiently dense, the vertical load will tend to shear roofing and cause leaks. This problem can only be prevented by reducing point loading or cutting the roofing and replacing the insulation under the sleepers with blocking, and then patching the roof. To date, sleeper installations have caused a high proportion of leaky roofs.

Guy Wire Anchorage. In the above case, light frame structure was designed, using sleepers (not attached to the roof structure) and guy wires to anchor everything in place.

Support Between Walls. Here the structural members span the space between available vertical supports. However, this design was revised to simple pitch pockets because spanning was not economical. Sometimes it may be economical, so one shouldn't discount it completely. If you do use this approach be sure to allow for temperature expansion.

Dead Load Anchor. Another interesting approach uses heavy dead-load concrete blocks tied together with structural members to withstand the horizontal forces of the wind. If the roof can support this structurally, it is an interesting approach, but you will pay an awful penalty in the cost of the extra roof structure required to handle the dead load.

Drainage Concerns. Remember that flat roofs are not flat; they pitch for drainage. If you decide on a continuous curb or sleeper arrangement, be sure to consider the effect on the roof drainage system. If puddling will ensue, make certain that the roofing material will not deteriorate. In general, coal tar derivatives will withstand puddling slightly better than asphalt. Neither, however, can be depended upon if submerged over long periods of time.

Shimming Requirements. Also, be sure to take into account the continuously changing roof slopes when designing the vertical components of the collector roof structure. Provide for shimming.

Design for Snow. In snowy areas, lifting the low point of the collector, collector support structure, and all piping sufficiently far off the road (based upon the amount of snow) allows the wind -- rather than maintenance personnel -- to remove the snow. If there are continuous collector obstructions next to the roof instead, they will tend to act as a snow fence and actually precipitate additional snow. This creates greater loads and reduces collector efficiency; buried collectors do not collect too well.

Design for Roof Maintenance. Raising the collectors also allows for future roof maintenance and repair. This is particularly important in

the south, where the collectors are installed at a very low angle for air conditioning.

Providing Roofing Protection. If protection for the roofing in the form of commercially available walking surfaces is installed where people tend to walk, the need to repair the roof will be reduced.

Collectors Access vs. Cost: Roof Mounted Locations. There has been a lot of expensive overdesign to provide instant access to the collector pipes and valves, especially in conjunction with tubular collectors. When working platforms are provided as part of the collector support, they are expensive and not cost effective. The use of a ladder has to be cheaper for access, but the roof surface must be protected from the point loading that ladders will create. There are no emergencies that require such instant attention that you cannot wait for a ladder. In fact, the condition will probably exist for a week before anyone notices it. If you have a real catastrophe, it is unlikely that the access walks will prove significant.

Ground Mounted Locations. Platforms on ground mounted arrays make even less sense and can create unsafe conditions when used in conjunction with ladders.

Pitched Roofs

Roof Pitch Less Than Collector. If the pitch of the roof is less than the desired pitch of the collectors, many of the same spacing considerations that we have encountered with flat roofs will exist. Namely, shade angles, structural loading, and snow problems must be considered.

Collector Pitch Same As Roof Pitch. If the pitch of the roof is acceptable for direct mounting of collectors, the design decisions are different because the collectors are mounted parallel to the roof. Spacing requirements are all but eliminated. The loading requirements are basically limited to the dead load of the collectors because the live load is not increased. Smow load is also no longer a problem, but avalanche protection must be provided for any unwary pedestrians that may exit from a building or walk by. Roof replacement under collectors cannot be done. All you can do to waterproof the installation is to protect the connection between the collector and the roof from water running down the roof.

Roof Attachment. With shingle roofs, the collector support points can be anchored with a plate under the shingles so that the fasteners are flashed by the shingles. If sleepers are used directly on the roof, they should not run across the slope of the roof or they will create a dam, retaining runoff and allowing water to penetrate the shingles. The sleepers should run with the slope, and if roofing cement is applied between each layer of shingles, under the sleeper and between the sleeper and the shingles, leaks should not occur.

Aesthetic Concerns. Typical aesthetic concerns when designing collectors on pitched roofs are: sloping collectors in drain down systems; the sheer amount of exposed piping on the roof; and provision for pipe crossovers.

Sloped Collectors. If a drain-down system is used, the collectors must be sloped to drain. Unfortunately, buildings do not slope; if the

designer does not consider this fact, people may wonder why the building is crooked.

Exposed Piping. For that matter, all piping should be considered in terms of aesthetic implications so that the final product does not look like an abandoned boiler factory.

Pipe Crossovers. Pipe crossovers should be avoided or carefully detailed because there is little room between the roof surface and the top surface of the collectors. Pipe crossovers invariably protrude above the collector surface, making them both highly visible and unsightly.

Ground Mounted Collectors

Ground or site-mounting raises the issue of buried piping versus above ground piping. In areas with a deep frost line or very wet soil conditions, locating piping above ground is much preferred. In fact, above ground locations are generally preferred to facilitate inspection and repair of piping, in spite of the thermal and water problems incurred. If piping is located above ground, however, the designer must contend with its appearance. In any case, when buried piping is used, try to minimize the amount of piping under paved areas (for obvious reasons.)

Cast Concerns in Site Supports. When collectors are mounted on the ground, the spacing considerations are similar to those for collectors mounted on a flat roof. Instead of roof penetrations one must contend with footings. In areas with little or no frost and good soil-bearing capacity, vertical supports are less costly than in deep frost areas, due to the difference in footing requirements. Here again, the designer should arrive at a good balance between horizontal structural spans and vertical supports.

Prefabricated Approach. For materials, consider pressure-treated wood as well as metals. We have found wood more cost effective. We have also found that a prefabricated horizontal structure supported by site-fabricated vertical members is a cost-effective approach.

Consider Specialized Approaches. In one design we reviewed, pole-barn-type vertical supports were least expensive. Due to the cost of footings, we have found it less expensive to install collectors in arrays two collectors high, again keeping the collectors off the ground for show and "growing things" clearance.

Maintenance Concern. Growing things, like weeds and trees, present a problem unique to site-mounted collectors. The cost and inconvenience of mowing your collector field could be considerable. Short of paving the area, one approach uses a chemical defoliant on the soil and follows with a covering of a plastic sheet and then gravel on the area.

Storage Locations: Liquid and Air Systems

For a long time we have known that a major loss of energy occurs through improper storage containers; IBM's data confirms our findings. Once the volume of storage and the area required is decided, the next decision to be made is the best available location. The choices are: above or below grade inside of the building, and above or below grade outside of the building.

Interior Storage

Above grade storage inside of the building is, obviously, the simplest location, if room can be found. However, the space required may cost $30 to $60 a square foot to build new construction, or it may take up valuable existing space. An interior installation is much easier to insulate and does not require waterproofing. Pipe runs also tend to be shorter.

Storage Tank Insulation. Aside from the physical space required, the main problem encountered in interior storage locations refers to the insulation of the tanks. This can be a twofold problem because valuable energy will be lost and, simultaneously, summer cooling loads will be increased. The most common source of heat loss is through radiation from the tank supports, either from legs, saddles, or the bottom of the tank. With tank saddles or tanks sitting directly on a slab, it would be advantageous to use a high density insulation such as foam glass between the tank and the saddle or the slab. If the saddles or legs are integral with the tank, it is best to insulate the supporting members. Then the supports should be isolated from the slab by using the neoprene or cork pads normally used as vibration isolators.

Wood Liquid Storage. We have not encountered liquid storage containers constructed of wood. However, our studies have shown that if properly lined with a sheet material such as EPDM, they should be cost effective and could solve many construction problems involving tight places for nonpressurized storage.

Concrete Liquid Storage. A number of designs have utilized either square or round concrete tanks with top, bottom, or mid-height joints. The major concerns with this type of tank are the construction joints and the porosity of the material. If the tank is supplied in two parts, be sure that the joint is well sealed. It is preferable that the two halves have grouted-in steel ties to prevent any movement that would cause leaks. In addition, the coating should be able to span minor cracks which often tend to develop. Cement and epoxy waterproofings would tend to be less desirable because they cannot span cracks. Liquid applied elastomerics or plastic liners are capable of spanning minor cracks and should be considered if the temperature and liquid water additives are compatible. Also, be sure to insulate the bottoms.

Exterior Storage

Once storage is removed from the building, the cost of the occupied space may be minimized, but problems and the chance of energy losses through storage are considerably increased.

Major Physical Concerns. There are a number of major physical factors related to exterior conditions which must be addressed:

Insulation. Ambient outside temperatures require close attention to insulation. The insulation should be impervious to water in case a leak develops in the waterproofing. If the tank is supported by the insulation directly on the ground, insulation must be capable of supporting the load of the filled tank without being crushed. If the tank sits on supports, it is doubly important to either isolate the support or insulate it in order to minimize radiation losses.

Waterproofing. Rain and snow demand close attention to water-

proofing. If the waterproofing fails, the insulation can be severely affected. All penetrations for valves, supports, piping, sensor wires, etc., must be adequately waterproofed in order to preserve the waterproofing, and therefore, the thermal integrity of the storage.

Freeze Problems. Freezing can be a problem, not so much for the storage tank (because of its mass), but for water piping without antifreeze. Freezing precludes the use of normal tank sight levels for monitoring the water level. If the sight level can be drained, however, monitoring is always possible. The maintenance personnel at all installations that we visited without some sort of level indicator have unanimously bemoaned their inability to ascertain liquid levels in storage.

Aesthetic Concerns. Aesthetic considerations of exposed storage tanks are unfortunately often neglected. The "Oh, it's in the back of the building, no one will see it" approach is often prevalent. Buildings have four elevations, and unless you are designing a plumbing warehouse, why make your building look like one?

Possible Design Approaches. We have seen well-designed screens; in one case, the storage waterproofing was white fiberglass reinforced epoxy and it looked very well as a free standing design element. Do not let your solar components happen; design them into your building.

Below Grade Storage

Buried tanks can be an attractive alternative. However, the concept of "out of sight, out of mind" can be misleading. Buried tanks save building space because of their exterior location and also eliminate aesthetic problems. However, they have more than their own share of problems.

Insulation and Waterproofing: Designing With a High Water Table. The first and foremost consideration prior to deciding on a buried location is elevation of the water table. If it is above the height of the bottom of the proposed tank, there are several problems which require a special hold-down structure and waterproofing. It is best to avoid this condition. However, if there is no alternative, you must design the support so that the tank is held up when full, and down when empty. This is usually accomplished with a large concrete footing with tank saddles to hold up the tank and steel straps to hold down the tank. It is most important that the supporting members do not break the waterproof integrity of the tank. One way of doing this is to insulate and waterproof the tank prior to installation. You must install high density insulation, such as foam and glass, capable of withstanding the point loads imposed by the supports and steel traps, and of strengthening the waterproofing in these areas. Remember that much as the support can crush the insulation and tear the waterproofing under the compression, the steel straps can do equal damage if the tank tends to float.

High and Dry Design. If there is no water table problem, there is probably no need for any concrete support, especially if the soil has good bearing and drainage. A common approach to installation is to pre-foam the tank with urethane, then wrap it with nylon fabric and a bitumastic material and set it in a sand bed. If done carefully, this seems to work well. Another approach is to set a tank in granular

insulation and place a plastic sheet over the top. If the surrounding ground is porous, this approach can work. However, if it is not, water will tend to back up into the insulation and extract your hard-won solar energy.

Access to Buried Tanks. Access to buried tanks is another area that must be thought out carefully. If access is required, many of the same freezing problems encountered with exterior above ground installations will be encountered here and must be solved. Again, if access is provided, and if the existing pipes, etc., are bunched, the access area can be minimized. Provide drainage between the walls of the access enclosure and the tank waterproofing so that water will not be trapped here.

Do Not Undermine Foundations. When locating your buried tank, especially in retrofits, be sure to locate it sufficiently far from the building so as not to undermine the foundations or footings. If the tank is located under existing slabs or pavement, the same problem exists. If you undermine a slab, it will ultimately crack or break up.

Do Not Undermine Slabs or Pavings. A good rule of thumb is to locate the tank at least 3 feet away from the face of the building. For each foot below the footing, you must excavate or provide slab openings of sufficient width, not only for the tank installation but also to prevent undermining. Check with the structural engineer for your particular site.

Structurally Integrated Concrete Storage Enclosure. In some cases we have found that designers have tried to integrate a concrete storage container into the general structure of the building by using the foundation walls and slab as the sides and bottom of the storage tank, while insulating only the outside of the tank inside the building.

Part of the Problem. This approach, though possibly less expensive, has related drawbacks. One is that there is a tendency to draw off and dissipate the heat through conduction within the adjacent concrete walls; this wastes heat in winter and can add to the summer cooling demand by radiating heat into occupied spaces.

Part of the Answer. This problem can be overcome only by first insulating the inside of the tank and then using a waterproof liner.

Air Storage.

Drainage and Visual Inspection. The question of drainage and inspection at the bottom of a rock box is often discussed. I, personally, do not see a need for a drain because drains have a greater potential for evil than good; they either back up or dry out. If a drain is provided, it must be primeable to prevent losing its trap and allowing sewer gases to enter the heating system. A better approach is to provide an opening in the duct that extends to the bottom of the box or a separate 3-inch diameter pipe, so that in emergencies a pump could be lowered. For the quizzical, visual inspections can be made; then, if perchance mushrooms are growing, they can be collected.

Insulating Concrete Tops. Another point that is not usually considered is how to insulate the concrete top of a concrete rock box. Be sure that there is sufficient space to get inside to remove the

formwork and install the insulation or design the insulation to act as the formwork.

Avoid Air Leaks. The most common problem we have found with rock storage, both in design and installation, involves proper sealing of wood cover to the storage box and of the duct penetrations. This problem is fairly easily overcome with a little detailing and thought. It is not sufficient to just run a bead of caulking around the duct penetration, especially if all you are caulking against is 1/2-inch plywood. Consider the paths that air can use to escape, and use some flashings, caulkings,glue, ingenuity to prevent it.

PIPING CONCERNS

Pipe Expansion and Contraction.

We know that there can be as much as 2 inches of movement on pipes due to temperature differential. These movements are either in opposite directions or at right angles to each other. Therefore, always allow for this movement at ties or in long pipe lengths.

Expansion Compensators. Some of the ways you can compensate for these movements are with silicone bulbs, bellows, braided wire, pipe elbows, or swings. Whatever method you choose, design it, show it, and specify it.

Pipe Support: Off Collectors. It is important to design the pipe support within the collector arrays. Pipes can be supported off the collector. This is normally done by the use of soldered copper nipples. Be very careful that the mechanic does not burn out the waterproof seals of the collector. We find this a constant problem because the solder required flows at a particularly high temperature.

Pipe Support: Off the Collector Support. You can also support pipes off the collector support. If you do, be sure to design space on the collector support to support the piping. You might consider supporting the pipes off the back of the support as an alternative.

Pipe Support: On the Roof. Sometimes, the pipes are just supported on the roof surface. If you try this approach, be prepared to use the pipes as a platform.

Pipe Support: Off Other Pipes. A fairly common way to support pipes is off other pipes, especially in reverse-return designs. In this case, be sure that the pipes are well supported, one from the other, and that they are both free to move independently. When supporting pipes, be sure to allow for thermal pipe movement. Do not restrain them by clamping pipes to waterproofing to the point where pipe movement will cause a tear in the waterproofing membrane. Pipe sleeves or shields should be considered to protect the waterproofing/insulation installation.

Bracing Pipe Anchors. In addition to supporting the pipes, if you are providing a pipe anchor, be sure that the structural member to which it is fixed is capable of resisting the design thrust resulting from the expansion compensator. Otherwise the structure may do the moving rather than the compensator.

Drain Down Systems

Design for Adequate Pipe Pitch. Drain down systems are very enticing because of their improved thermal performance. However, there is one overriding physical requirement which must be met but is sometimes overlooked--all the piping and collectors must be adequately pitched to drain. We have seen designs where there is no provision, or even enough room on the collector support, for pitching the collector or piping. The specifications, however, state that all piping must pitch to drain. If your design required drain down, then your detail must allow for pitch or it will not drain down. And remember that the piping will not be installed by watchmakers.

Allow for Structural Deflection. Keep in mind, too, that collector supports are allowed to deflect under loading--so when designing the collector support allow sufficient space to adequately pitch piping. Also keep in mind that 1/8-inch per foot slope parallel to the collector slope is less than 3/32-inch in actual vertical drop. If possible, 1/4-inch per foot pitch is a good slope to design.

Pipe Insulations. Most of the insulations that solar designers deal with were not developed for the solar field. They are being used and adapted to solar but are not really suitable in all cases. Let us look at some of the problems.

Rigid Fiberglass. Rigid fiberglass is a very common material. It is relatively low cost, varies in thickness up to 3 inches and resists high heat. On the other hand, it absorbs water like a sponge and once wet makes a better radiator than an insulator. Also, it cannot take the flexible shapes very often required by solar installations. This material is good for long runs of piping without too many joints and tees, but it is especially unsuitable for exterior manifolded collector installations due to the inherent problem of providing adequate waterproofing.

Rigid Foam. Rigid foam is roughly comparable in cost to rigid fiberglass for the same R value. Like fiberglass, it too varies up to about 3 inches. However, it greatly deteriorates if exposed to the high heat associated with stagnation. Should stagnation be a possibility, you might consider some sort of pipe wrap as an inner protection. Rigid foam is not readily affected by water, but it is also not waterproof. As a matter of fact, water coming in contact with some rigid foams and pipe will create a mild acid which will deteriorate the pipe, so it must be well waterproofed. Rigid foam also cannot take the flexible shapes that are often required with solar.

Flexible foam is available in very limited thicknesses: only 1/2-inch or 3/4-inch. If you want to better the R value, you must put on a second layer at double the cost. It is affected by high heat; possibly, the use of pipe wrap would aid in this problem. It is not affected by water; it is waterproof and can be used as its own waterproofing. However, it is affected by the sun's ultraviolet rays. It can be painted to protect against ultraviolet deterioration. If you do not paint it, serious deterioration is often seen in 6 months with failure within a year. A final advantage of flexible foam is that it is capable of taking any shape necessary. This material is particularly suited to exterior uses involving many bends, short sections or penetrators, such as we encounter with exterior manifolds or interconnecting collectors.

Pipe Waterproofing. Common areas that require special provision for waterproofing are joints between collectors and piping, at changes of direction in pipes, pipe trees, and where valves or monitoring equipment protrude through the waterproofing. Be sure that your design and contract documents fully address these problems.

Do not allow open seams in waterproofing. Provide joint protection at all elbows and tees.

Don't Bind Waterproofing. Do not bind your pipes when supporting them. Be sure that the pipes are free to move or, with pipe movement, you will either tear your waterproofing or insulation.

Don't Puncture Waterproofing. Do not support piping by puncturing your waterproofing; especially in terms of supporting the pipe directly. Not only do you puncture the waterproofing and wreak havoc with the insulation, but you also allow for a heat bridge to radiate additional energy. Support the pipe loosely on the outside of the waterproofing.

Don't Just Seal Over Joints. Do not seal over the ends of sheet waterproofings. Seal between the seams or the sealant will fail with movement. Seals over waterproofing layers will fail; seals between waterproofing layers will tend not to fail.

Avoid Differential Metal Contact. Lastly, avoid differential metals, if you are using aluminum waterproofing. And, if you have steel structures or steel clamps, be sure that you have nonmetalic protection to prevent galvanic action. We saw one installation where aluminum waterproofing with a sheet of galvanized steel under it had no galvanic protection between them. That waterproofing will fail.

The final insulation-waterproofing approach you select should answer all the requirements of the installation factors of your design.

CONCLUSION

Cost Considerations

The designer of a solar installation does not necessarily have to trade off good aesthetic design for cost or vice versa, but he/she must consider each solar component and its ultimate impact on the function and appearance of the building, and work toward an attractive and cost-effective solution. He/she must then fully transmit this solution to the contractor.

Construction Considerations

There is a lot more to designing an effective solar-assisted mechanical system than just choosing your collector area and mechanical approach. A successful project demands a high level of attention to all details.

DOE/CS/4281-1

Second Draft

Model Document for Code Officials on Solar Heating & Cooling of Buildings

September 1979

Prepared for
U.S. Department of Energy
Assistant Secretary for Conservation
and Solar Applications
Office of Solar Applications
Washington, D.C. 20585

Under Contract No. EM-78-C-01-4281

Prepared Jointly by:

- **Council of American Building Officials**
- **Building Officials and Code Administrators International, Inc.**
- **International Conference of Building Officials**
- **National Conference of States on Building Codes and Standards, Inc.**
- **Southern Building Code Congress International, Inc.**

All proposed changes to the second draft must be submitted to the Council of American Building Officials on the comment sheet attached to the back of this document not later than December 7, 1979.

The Appendix contains substantial reproductions from the following publications:

THE BASIC MECHANICAL CODE, copyright 1979, published by the Building Officials and Code Administrators International, Inc.

THE I.C.B.O PLUMBING CODE, copyright 1979, and THE UNIFORM MECHANICAL CODE, copyright 1979, published by the International Conference of Building Officials.

THE NATIONAL ELECTRICAL CODE published by the National Fire Protection Association.

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PATENT STATUS

This technical report is being transmitted in advance of DOE patent clearance and no further dissemination or publication shall be made of the report without prior approval of the DOE Patent Counsel.

TECHNICAL STATUS

This technical report is being transmitted in advance of DOE review and no further dissemination or publication shall be made of the report without prior approval of the DOE Project/Program Manager.

FORWARD

The Solar Energy Document is the result of a contract between the Council of American Building Officials (CABO) and the U.S. Department of Energy (DOE). The funding support provided by DOE enabled this document to be developed as a useful guide in the code enforcement field using the state of the art now available in the solar energy field.

The primary purpose of the document is to promote the use and further development of solar energy through a systematic categorizing of all the attributes in a solar energy system that may impact on the nationally recognized model codes, particularly to those provisions relating to the safeguard of life or limb, health, property and public welfare.

Although solar energy systems are inherently provided for in the model codes it is necessary to develop these guidelines not only as an aid to the enforcement official, designer, consumer and builder, but also as an instrument to promote further research in solar energy and the development of meaningful new standards.

The Solar Energy Document was developed using concensus procedures which provided for balanced representation from the consumers, public interest groups, professionals, builders, code enforcement officials, manufacturers, energy suppliers, standards organizations and material suppliers, The initial

which could materially affect its use as a solar collector. Therefore any attempt to identify those provisions in this document which apply to both passive and active solar energy systems would be a recapitulation of the building, plumbing and mechanical codes which might well impede the promotion and development of solar energy. For that reason provisions have been included which require solar components serving as building components to comply with the building code and when connected to the heating, ventilating and air conditioning or plumbing systems to also comply with the applicable provisions of this document.

In the design of solar energy systems it should be recognized that some pressure vessels may be of a size and pressure that will come under the requirements of existing boiler and pressure vessel laws in some jurisdictions. In such instances, the design and construction of the pressure vessels must conform to those requirements.

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APPENDIX C

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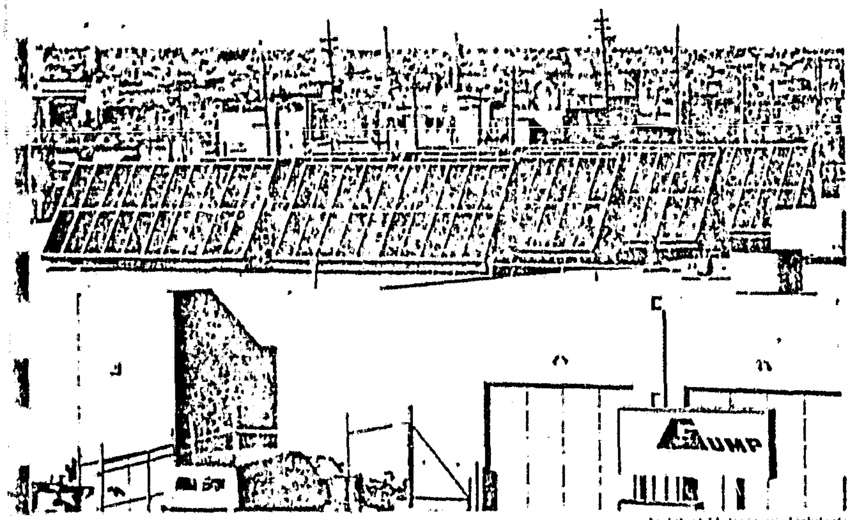
ASSEMBLY

INDUSTRIAL AND AGRICULTURAL PROCESS HEATING SYSTEMS

SOLARON®
SOLAR ENERGY SYSTEMS

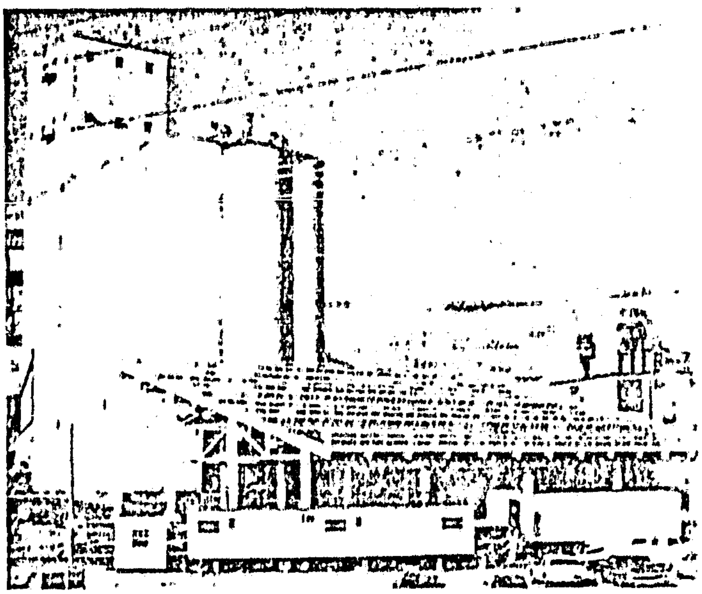
TM



Architect / Intergroup Architects

INDUSTRIAL APPLICATIONS

- Make-up air heating
- Process hot water heating
- Outside air heating for process drying
- Wash water heating
- High temperature air and water preheating and tempering



Designers / Teledyne - Brown Engineering Co

AGRICULTURAL APPLICATIONS

- Grain Drying
- Wash Water Heating
- Agricultural Building Heating
- Make-up Air Heating
- Food Process Heating

MR-MANUFACTURER

Solaron Corporation is an international marketing and manufacturing company, recognized as a world leader of air-type solar heating systems based upon over 20 years of continuous proven performance.

PP-PRODUCT PRESENTATION

We are borrowing time on conventional fuels as their prices skyrocket and availability is less secure. America is energy dependent—oil used today is subject to political interruptions. The sun has burned for 5 billion years and will burn for 5 billion years more. No nation can embargo or form cartels of this inexhaustible energy source.

America's traditional individualism is based upon an energy structure which is eroding. Prudent business strategies are reducing dependence on single energy sources.

SOLAR ENERGY is a means to energy independence, to capitalize future energy and a counterattack to inflated production costs.

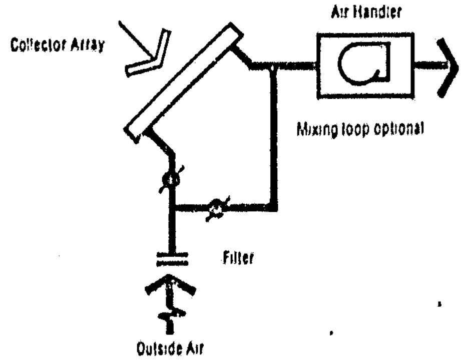
Solar energy will heat your space, your hot water and your industrial and agricultural processes. It can be a cost-effective means of providing a fixed percentage of tomorrow's energy requirements at today's prices.

Solar energy, properly designed and applied, can:

- Provide dependable, reliable and proven energy for many years.
- Offer the lowest life-cycle cost of any conventional energy source.
- Stabilize operating costs and cash flow because of predictable energy bills.
- The cost of the solar system is fixed, thus future solar-derived energy costs can be predicted, capitalized and controlled.
- Provide environmentally pure, socially acceptable energy.

Design Assistance: Solaron has a complete design manual covering all aspects of solar system engineering, architectural requirements and economics. Contact Solaron for a copy of the design manual. Experienced and technical personnel are available to assist on any special applications.

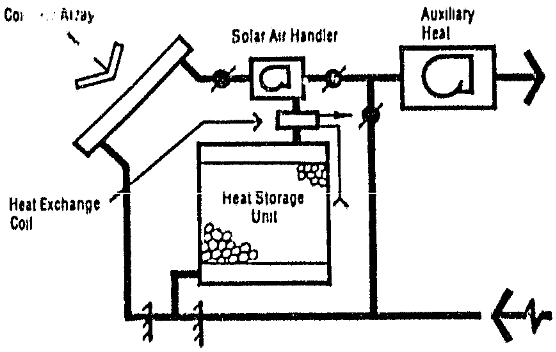
Solaron Solar System Descriptions and Example Applications



MAKE-UP AIR AND PROCESS HOT AIR HEATING

Heating outside air is often the simplest, most cost-effective use of the Solaron system. Outside air is drawn or blown through the collector array where the air is heated. BTU delivery is maximized in this system since the inlet air is at ambient temperature, thereby reducing losses from the collectors.

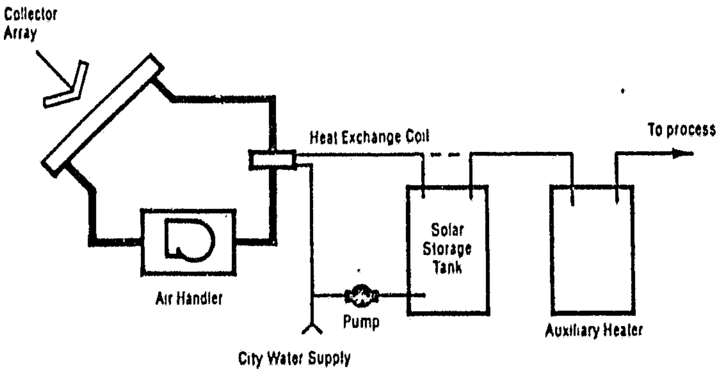
APPLICATIONS
- Make-up Air
- Process Hot Air for Industrial Drying
- Agricultural Air Drying



SPACE HEATING AND WATER HEATING

Solar energy can economically provide a significant portion of space heating needs in most areas of the country. Heat stored in the rock storage bin supplies heat at night and on cloudy days. Water preheating is suggested to utilize solar energy during the summer and when space heating is not required, thereby improving system economics.

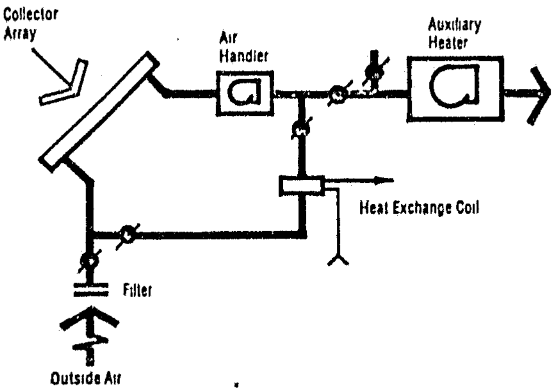
APPLICATIONS:
- Comfort space heating and water preheating.



PROCESS WATER HEATING

Heating water for industrial and agricultural process applications is an excellent way to utilize the Solaron solar system since the hot water is required throughout the year, maximizing the solar utilization. Using an air collector to heat water eliminates the freezing, boiling, corrosion, leaking and expansion problems found in liquid solar collectors, thereby reducing maintenance and extending the useful life of the system.

APPLICATIONS:
- Domestic Hot Water
- Service Hot Water
- Tempering water for steam boiler makeup



COMBINED MAKE-UP AIR OR PROCESS HOT AIR HEATING AND PROCESS WATER HEATING

This system combines outside air and water heating. The combined system is often preferable in order to utilize the solar system throughout the year. In cases where hot air demands are intermittent, the system stores energy for hot water requirements.

APPLICATIONS:
- This system combines the applications for make-up air/process hot air heating and process hot water heating listed above.

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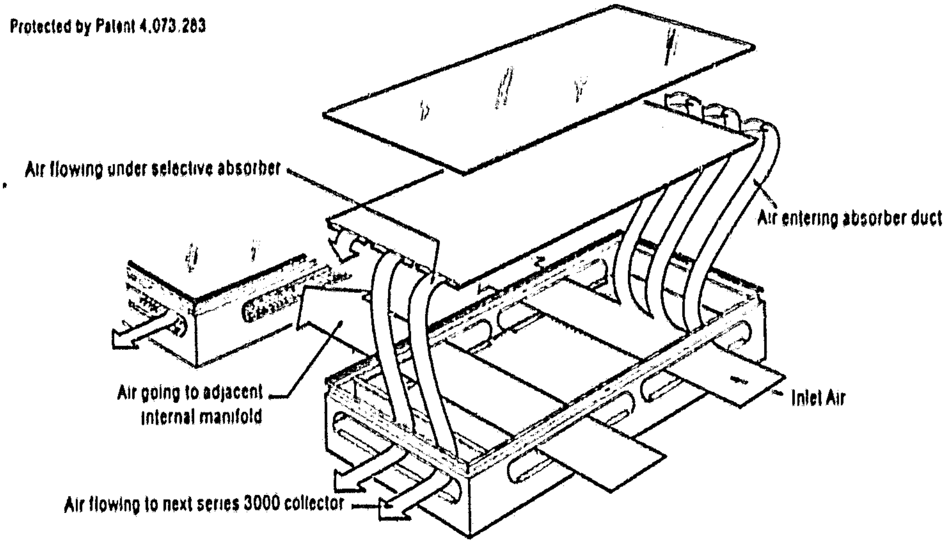
SOLARON®
SOLAR ENERGY SYSTEMS

Series 3000

An Air Heating Solar Collector With A Patented Manifold System.*

Protected by Patent 4,073,283



FEATURES
- High Thermal Efficiency.
- Black Chrome Selective Absorber Surface.
- Durable Construction.
- Uses Air for Reliability and Long Life.
- No Pipes to Corrode or Freeze.
- Factory Assembled.
- Labor Saving Internal Manifold.
- Simple Installation.
- Suitable for Retrofitting.
- Architecturally Attractive.

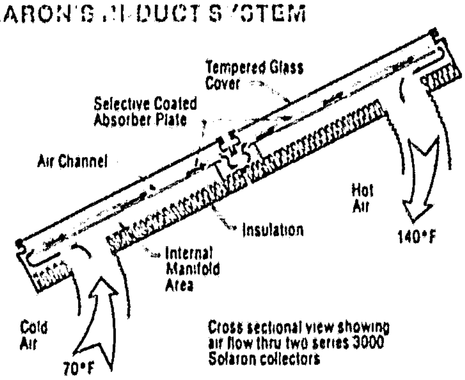
PRODUCT DESCRIPTION
- The air flow in the Series 3000 collector passes beneath the absorber in a duct that is formed by the absorber and a second metal sheet. This allows the selective coated absorber to be insulated by a dead air space between it and the glazing. This design makes for a more efficient collector in most applications and protects the absorber surface from dust or other airborne contamination.
- The collector utilizes a patented air manifold system to minimize field installation labor and assure uniform high performance.
- The manifold system replaces most of the ductwork normally used to interconnect air heating collectors.
- Will withstand rain, hail, snow and wind loads present in most parts of the world.
- Developed in over thirty-five years of research and testing.
- Performance determined by a prominent Independent testing lab.**
- Accepted for federally funded space and water heating programs.

SPECIFICATIONS
- Collector Model Numbers
  - —CL3011 - for 2 high arrays or outside rows of 3 high arrays
  - —CL3013X - for 1 high arrays when paired with 3013Y
  - —CL3013Y - for 1 high arrays when paired with 3013X
  - —CL3014 - for inner row in 3 high arrays
  - —CL3015 - for large 1 high arrays
- Gross collector area—18.75 square feet
- Aperture area—17.07 square feet
- Ratio of aperture area to gross area = 0.91
- Glass Cover
  - —⅛ in. thick
  - —Tempered low iron
  - —Solar Transmittance 0.89
  - —Lightly textured
- Absorber Coating—black chrome over nickel
  - —Absorptivity 0.95 minimum
  - —Emissivity 0.15 maximum
- Recommended Air Flow Rate through Collector
  - —2 to 3 SCFM/ft ^{2} of collector
  - —37.5 to 56.25 SCFM per collector
- Insulation—Fiberglass
  - —2.5 inches batt
  - —0.5 inch semi-rigid foil backed
  - —R13 insulation value
- Collector Net Weight
  - —135 pounds
  - —7.2 pounds per square foot
- Collector Shipping Weight
  - —280 pounds per package of 2 collectors

*An "air heating solar collector" is a solar collector which uses air to carry heat from the collector absorber to the point of use or storage. There are no liquids circulated in the collector.

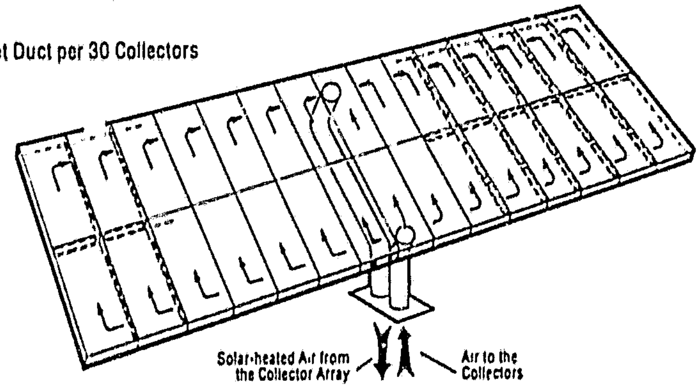
**Name and report available upon request.

SOLARON'S 1 DUCT SYSTEM

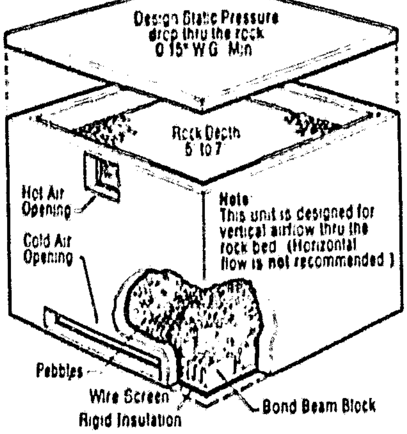


Cross sectional view showing air flow thru two series 3000 Solaron collectors

1 Inlet & 1 Outlet Duct per 30 Collectors



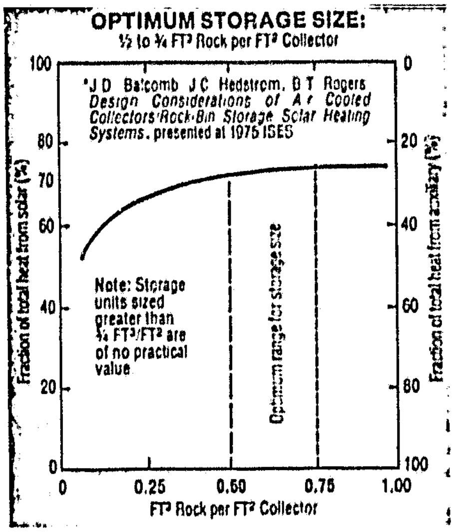
Solar System Performance



PEBBLE-BED HEAT STORAGE UNIT

The pebble bed allows heat to be stored at nearly the outlet temperature of the collector. This is possible because of the high degree of stratification exhibited by the pebble bed and the flow direction reversal between "storing heat" and "heating from storage."

When "storing heat," the high temperature air from the collector outlet enters the top of the pebble bed where it gives up its heat to the pebbles and returns to the collector as cool air. This allows the collector to operate at the highest possible efficiency.



The heat storage unit must be built and installed by the local contractor to Solaron standard drawings and specifications. Contact Solaron for a copy of these specs.

A SYSTEM APPROACH

Solaron Corporation is unique in that it is a system company. In addition to the Series 3000 collector, the company provides:

- **AIR HANDLING UNITS:** The blower and its necessary accessories are sized to be compatible with the Solaron system.
- **CONTROLS:** To work properly, the system must have controls with the logic to automatically operate in all modes. This is provided by Solaron and eliminates errors in this critical function.
- **ALL COLLECTOR HOLD-DOWN HARDWARE:** Solaron literally provides all the nuts and bolts required for installing the collector panels. Hardware not manufacturer-provided is material normally used by the mechanical contractor and readily available.

TS-TECHNICAL SUPPORT

HEATING OUTSIDE AIR WITH SOLAR COLLECTORS

One of the most efficient ways of using a solar collector is to heat outside air required for ventilation, make-up air, process heating or drying applications.

The best solar collector to use for air heating is an AIR heating collector since it does not need the added heat exchange process that liquid-type collectors require.

Heating outside air with an AIR heating solar collector is an excellent utilization of a solar heating system because the collectors operate at a low inlet temperature and thereby have minimal losses. This means that the solar system is operating very efficiently since little energy is lost due to the temperature difference between the collector panel and the ambient air temperature. This can be explained by the following equation which shows the solar collector performance.

$$\frac{Q_u}{A_c} = F_R[H_T \tau\alpha - U_L(T_i - T_a)]$$

WHERE:

- Q_u = Solar collector output (BTU/Hr)
- F_R = Heat removal factor for a specific collector
- A_c = Area of the collector panels (ft²)
- H_T = Average amount of solar radiation falling on a tilted surface $\left(\frac{BTU}{Ft^2\,Hr}\right)$
- τ = Cover transmittance
- α = Absorber plate absorptance
- U_L = Overall loss coefficient
- T_i = Fluid inlet temperature to the solar collectors
- T_a = Ambient temperature around the collectors

When an AIR solar collector is used to heat outside air, the fluid inlet temperature (T_i) is equal to the ambient temperature (T_a) since the collector is drawing in the ambient air and heating it as it passes through the collector panel. Therefore, the losses, $U_L(T_i - T_a)$, are essentially zero [$U_L(T_i - T_a) = 0$ when $T_i = T_a$] and the collector is at peak performance.

$$\frac{Q_u}{A_c} = F_R[H_T \tau\alpha]$$

Therefore, using an AIR heating solar collector to heat outside air is an excellent utilization of a solar system and can be very cost effective.

WHY USE AIR TO HEAT A LIQUID?

An AIR system can, in many applications, equal or even outperform a liquid system.

- A liquid collector needs protection from freezing, boiling and corrosion. Therefore, most end-use liquids cannot be directly circulated through the panels.
- Normally, a non-freezing liquid is circulated through the panels. Often, this liquid must not come in contact with the process fluid. Therefore, a two-stage heat exchange process is required to avoid contamination in case of a leak in the antifreeze loop.
- To heat liquids, an air collector uses one high-efficiency heat exchanger.
- *One* heat exchange process with an AIR system is comparable in efficiency with the *two* heat exchangers often required in a liquid solar heating system.
- Liquid solar system antifreeze solutions must be periodically checked and replaced.
- Liquid collectors must be protected from adverse stagnation pressures.
- Little or no maintenance in an AIR system.

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SOLARON®
SOLAR ENERGY SYSTEMS

T.M.

300 GALLERIA TOWER
720 SOUTH COLORADO BLVD.
DENVER, CO 80222 • (303) 759-0101 • TWX 910-931-2580

Printed in U.S.A.

APPENDIX D

AN OVERVIEW OF LEGAL ISSUES RELATED TO USE OF SOLAR ENERGY SYSTEMS*

William A. Thomas
American Bar Foundation
1155 East 60th Street
Chicago, illinois 60637

*This paper with some modification has been published in 83(6) Case & Comment 3 (1978). It summarizes material presented in greater detail in W. Thomas, A. Miller & R. Robbins, Overcoming Legal Uncertainties About Use of Solar Energy Systems (American Bar Foundation, 1978).

AN OVERVIEW OF LEGAL ISSUES RELATED TO USE OF SOLAR ENERGY SYSTEMS

Introduction to the Legal Issues

Use of solar energy systems for a variety of purposes offers a partial solution to the national energy problem. These systems consume only small amounts of conventional fuel and produce no pollutants. Like any developing technology, however, they raise legal issues that must be resolved before we can satisfy our expectations for this promising source of energy.

An effective assessment must encompass a wide range of questions, and we found it helpful to group these legal issues into five classes. These classes certainly are not mutually exclusive, and they often overlap considerably.

(1) Regulation of building materials and design. Two well-established procedures are used to draft building codes for residential and commercial structures. The first sets "prescriptive standards" that designate specific building materials and how they are to be used, such as specifications for type and installation of electrical wiring. The other method is to establish "performance criteria," which are descriptions of what the materials or design must attain. The latter method is keyed to function rather than design, and architects and engineers prefer it because it allows more flexibility and reduces financial burdens. Many building codes contain provisions which inhibit building designs and components that are necessary for cost-effective and aesthetically pleasing solar energy systems. Building codes also would help promote solar homes if they provided incentives or requirements to conserve energy.

A related topic is private or public regulation of the appearance of solar energy collectors. This issue commonly arises when a local government requires that an architectural review board, or a similar panel, approve all designs for new construction or reconstruction. Similarly, homeowners' associations and other private organizations that exercise control over land-use characteristics might require that landowners submit plans for new construction or material changes in existing structures to a review panel for approval. The purpose of these provisions, of course, is to perpetuate desirable neighborhood characteristics. These requirements, however, can inhibit the installation of solar energy collectors if their design is perceived to be less than architecturally pleasing by members of the public or private panels. This outcome has resulted in strained community relations and litigation in several instances.

(2) Financing and marketing arrangements. Considerations such as property and sales taxes, mortgage and depreciation rates, warranties on equipment, and insurance rates can function as barriers or as incentives for using solar energy. We have limited experience with producing, marketing, installing, maintaining, and financing solar energy systems, and this inexperience itself inhibits greater use of solar energy.

Fortunately, this situation is changing. We should act forthrightly by designing incentives--such as tax credits and deductions and loan and

interest rate guarantees--to counteract specific barriers. Most of the proposed state and federal legislation to date is designed to do this.

Another consideration is how labor unions will allocate the production, installation, and maintenance of solar units among crafts. What is a rooftop solar collector? Part of the roof, part of the plumbing system, part of the electrical circuitry, part of the heating and refrigeration system, or part of all four? This definitional problem also arises when the collector must be classified under property and other tax laws.

(3) Role of public utilities. The backup energy source needed in conjunction with solar units directly involves the public utilities. Rate structures equitable both to the utilities and to the small and intermittent user of their services are needed. This policy issue must be faced soon, as must some others. Should the public utilities be encouraged to use solar energy systems? Should solar energy cooperatives be formed under present or new utility regulations? If several neighbors get together to install a solar conversion system to distribute energy only among themselves, would they be subject to regulation as a public utility? We need more experience to answer these questions, but it is unlikely that we will get more experience without dependable assessments of what would result from proposed regulatory actions.

(4) Land-use planning. A series of problems that local governments must face concerns the restraints that constitutionally can be imposed on the use of privately owned land. Land-use regulations can control the actual and potential use of land and size, placement, and design of the solar collectors. People who plan to retrofit existing structures to use solar systems might encounter problems because regulations frequently limit changes on existing buildings. New large-scale developments--such as subdivisions, shopping centers, and industrial parks--usually must satisfy another set of regulations that control placement of buildings and other structures, their uses, and their style and aesthetics, and that outline what the developer must provide in the way of public utilities and other services. If this is done correctly with proper planning, the result is not only an attractive development but also one that conserves energy. In fact, solar energy could be encouraged, or even required, by offering financial inducements or other incentives that are limited only by the human imagination and constitutional guarantees.

Land-use regulations are subject to change, and it normally requires only three readings by the local legislative body to change them drastically. Newer procedures in land-use planning to protect property characteristics that favor use of solar energy include comprehensive plans, transferable development rights, official mapping of solar districts, and planned unit developments.

(5) Access to sunlight. This really is a subset of the previous category, but it obviously is a central issue that must be considered in detail. The main conclusion of the ABF study cited above is that the single most important legal issue is guaranteeing access to sunlight for solar energy collectors. Other questions can be resolved by the private marketplace and the political process in the normal course of events as we gain experience with this new technology.

Access to light in many situations might not present any problem

whatsoever, as in the case of a collector on top of a building centered on a large lot in a nonurban area. However, in many other circumstances, particularly where a landowner cannot predict accurately or control legally the uses to which neighboring land will be put, a prudent person would hesitate to invest in a solar energy collector until a "right to light" was assured. Architectural and system design features, topography, trends in land use and vegetative growth, and other factors also should be considered in determining whether additional legal protection of solar skyspace--that area between the collector and the sun during critical daylight hours--is advisable and practicable.

It is important to note at the outset that direct sunlight does not impinge anywhere in the United States from directly overhead. Reflected and diffuse light is available from overhead, but this is insufficient for cost-effective operation of solar energy collectors. This physical circumstance accounted for much of the confusion in early legal doctrines concerning access to sunlight. Since it often is helpful to consider legal topics in historical perspective, the development of two doctrines concerning access to sunlight are outlined here before the current status of the law is described.

(a) A legal maxim. Many centuries ago, the Latin maxim Cujus est solum ejus est usque ad coelum et ad inferos had been incorporated into Roman, German, French, and Jewish law. The use of the maxim dates from antiquity and means, "The owner of the soil owns also to the sky and to the depths." That is, the owner of the surface was considered to own from the center of the earth to the heavens.

Then, in 1586 an Englishman named Bury lived in a house built near the property line with a window through which he had received light across adjacent land for 30 or 40 years. His neighbor, Pope, decided to build a house so near the property line that it would prevent light from entering Bury's window. Bury went to court, claiming that Pope shouldn't be allowed to build his house there because Bury needed the light. The justices in a very short opinion said that Bury should have foreseen the consequences of building so near the property boundary and that Pope could build anywhere he pleased on his own land, even if it obstructed light that otherwise would cross the property line. The report of the case concluded with a version of the Latin maxim, and it has been part of Anglo-American law ever since.

A long series of cases since then confirms that overhanging tree branches, roof eaves, and similar objects constitute trespasses. In one case, a person having an altercation with a neighbor struck him across the fence between their properties and was charged not only with assault and battery, but also with trespass, because her fist had penetrated the airspace over her neighbor's land.

This legal situation quite obviously is incompatible with aviation, and in the first half of this century the maxim was gradually weakened by courts and by the Congress to accommodate the new technology. As Justice Douglas explained, in reference to the maxim in 1946, "[T]hat doctrine has no place in the modern world. The air is a public highway, as Congress has declared. Were that not true, every transcontinental flight would subject the operator to countless trespass suits." The law was modified by necessity. Landowners can control airspace over their property only as far as is needed for reasonable use and enjoyment of the surface as determined on a case-by-case basis.

(b) Doctrine of ancient lights. A second legal rule concerning right to receive light is the doctrine of ancient lights that English judges evolved over the centuries. Under this doctrine, property owners are entitled to receive light across adjacent land up to the amount needed for reasonable use and enjoyment of their own land if they have received that light for a specified period of time. In early common law this period was described as "from the time when the memory of man runneth not to the contrary" or as "the time before which no man has memory," which merely meant that the light had been received for a very long time and that no one could remember anyone having blocked it. If the landowner had received light for that period of time, a neighbor would not be allowed to obstruct it unreasonably. In the early English case noted above, Bury evidently could not prove that he had received light for this period and therefore could not prevent Pope from blocking it.

The required uninterrupted time of enjoyment varied with English legal history until it was codified at 20 years in 1832; it was lengthened to 27 years in 1959. Rather than requiring landowners to construct barriers to prevent the right from accruing to neighbors, the filing of notice by a landowner now substitutes for the erection of an actual barrier. This facilitates urban planning and protects individual property values by greatly reducing uncertainties.

The real question facing English judges is how to define reasonable use and enjoyment. This obviously must be done on a case-by-case basis, and the cases refer to "substantial deprivation" and stress that the amount of light remaining, not the amount blocked, is the important factor. The English devised an ingenious concept known as the "grumble line" to assist in determining when substantial deprivation would occur. This line is located in a room at that distance from the window where an ordinary person reading ordinary print would grumble and turn on the light. The rule-of-thumb is that a reasonable amount of light is left if at least half of the room is between the window and the grumble line. Engineers have determined that this line is approximately where the light intensity equals 1 foot-candle at the top of a desk 33 inches (84 cm) high.

Some colonial courts in the United States did enforce the doctrine of ancient lights, but it soon was repudiated in most states as being inconsistent with a growing and dynamic country. However, in at least one state, Delaware, this status of the doctrine was not certain until as late as 1939. Although the doctrine of ancient lights is not part of American law, consideration of experience with it in England and elsewhere is useful for several reasons. First, the factual situations in cases arising under the doctrine illustrate the range and types of circumstances that produce legal conflicts about access to light. Second, the doctrine has been proposed by some legal writers as the basis for new laws to encourage use of solar energy systems--that is, they seem to suggest that the doctrine should not be considered dead but merely in repose.

(c) Current law. A review of an illustrative case might help explain the current status of the law. The Fontainbleau Hotel was constructed in 1954 in Miami Beach, and the Eden Roc was constructed the following year immediately north of and adjacent to the Fontainbleau. Several years after construction, the owners of the Fontainbleau decided to add 14 stories on the northern portion of their property. Doing so would cast a shadow during winter for most of the afternoon over the swimming pool, sunbathing area, and cabana of the Eden Roc. Not surprisingly, the Eden Roc sued, claiming that they had a right to continue receiving the light

across the Fontainbleau property. A lower court enjoined the Fontainbleau on the principle that a property owner could not use property in a manner that would cause injury to another, but a Florida appellate court held otherwise. The judge said in essence that, although it is true that one person is not allowed to use property in violation of the rights of another property owner, the Eden Roc had no rights that were being violated because the doctrine of ancient lights is not recognized in this country.

The law in a nutshell in the United States is that landowners have a right to receive sunlight from directly above their property but not from across adjacent property. Adjacent landowners can construct buildings, plant trees, erect fences, or otherwise block sunlight as long as all other aspects of the action are reasonable and legal. While it is true that every property owner might benefit from a change in the law, we must keep in mind that every property owner also would bear the burden of providing the benefit to others. Reduction in land value because of the reduced opportunity to develop it would not in all instances be offset by the added value provided by the guarantee to receive direct sunlight.

The technology in a nutshell is that the direct and diffuse light from across neighboring land is necessary for efficient operation of solar energy collectors. The challenge is to encourage private and public remedies for this disparity between what the law provides and what the technology requires.

Private remedies range from outright purchase of adjacent property, or purchase of air rights above that property, to negotiation of an easement for light to protect access to sunlight. An easement is a property right with all the formalities of other legal interests in real property and is considerably more than mere permission to do something which can be revoked at any time. In an affirmative easement--such as a right-of-way--the purchaser has a right to enter the land of the seller to the extent specified in the easement. In a negative easement, however, the purchaser cannot enter the seller's land but can prevent the seller from doing something on the land that would be permissible if the easement did not exist. An easement for light is a prime example of a negative easement. The purchaser of the easement cannot physically enter the land but can legally prevent the other landowner from erecting structures or growing trees, for example, into the space protected by the easement.

An important distinction between the two types of easements is that affirmative easements can be created without negotiation under appropriate circumstances. If, for example, a person has been openly and routinely crossing the land of another for a number of years--normally 20 in most jurisdictions--and the landowner has not complained, then a right-of-way by prescription is established. Easements for light, as is true for all negative easements, cannot be acquired by prescription but must be negotiated and created expressly.

It might be economically feasible to purchase easements for light from adjacent landowners in areas where the development potential of the land will be low for the foreseeable future, but they certainly are inapplicable in urban areas where the cost of an easement could nearly equal the value of the entire property. It is possible, of course, to purchase an easement only at such a height above the ground that it would be economically practical. The costs and difficulties of negotiating

satisfactory private agreements between property owners could limit their appeal. Reliance upon them would require a multitude of successful transactions if widespread use of solar energy were to be encouraged. Nonetheless, the private marketplace definitely should be considered in conjunction with public remedies.

Congress is not likely to nationalize airspace any lower than is necessary for commercial aviation because of conflicts with private property rights. Local and state governments, however, can preserve unobstructed airspace through present and new land-use controls, such as creation of solar zones and inclusion of open-space provisions in community plans. Current height restrictions and setback requirements could be implemented with this goal in mind. Taxing authorities could assess land on its income-producing value, rather than on what it could produce under what is sometimes called its highest and best use. For example, some states have attempted to preserve open spaces in this manner by taxing agricultural land in suburban areas at its actual income-producing value rather than at the value it would produce if fully developed.

Governments can acquire land by eminent domain with just compensation, but only for public use. They could not, for example, take a person's yard to keep it free of obstructions to a neighbor's solar collector. It might be possible to adopt a policy to the effect that use of solar energy collectors is of such importance to the community that eminent domain could be used to acquire airspace above critical parcels of land. This must be accomplished in a manner that provides a public benefit and not just a windfall to the select few with solar collectors.

Local, state, and federal legislative bodies have considered a variety of proposals to overcome existing laws concerning access to sunlight. Some of these provide direct legal assurances, while others offer various incentives to subordinate governmental units to guarantee some access to light. Public intervention in the marketplace in effect redefines property rights and mutual obligations among landowners. It decreases or eliminates transaction costs and, if performed equitably, would result in no aggregate decrease in property values if the limitations on property rights are exceeded by the correlative gains. To promote this happy result, it will be necessary to assess very carefully the prospective effects of any public action. For instance, control of vegetation that might shade a solar collector is a particularly troublesome problem because of the attitudes of landowners about the aesthetic value of trees.

The very least that a state legislature can do is specifically authorize local governments to consider access to sunlight when designing their various land-use regulations, including the comprehensive plan. Oregon was the first state to include this specific provision in its enabling legislation that delegates state authority to local governments. This language, which specifically relates the use of solar energy to the public health, safety, and welfare, allows local governments to plan under state authority for a purpose that otherwise might not receive judicial approval.

A current phenomenon within legal circles is the desire to draft "model legislation" to cure almost any perceived ill that comes along. The general area of solar energy and the law is no exception. To the best of my knowledge, no one has advanced "model legislation" in the sense that it is designed to be considered for enactment by state or local governments without modification to accommodate prevailing conditions. The

ABF report includes four suggested statutes, three of which could be used to promote effective land-use regulations and to encourage use of solar energy systems. Several local governments have been active in drafting, considering, or sponsoring the drafting of ordinances and regulations for this purpose.

Conclusion

These, then, are the main legal issues related to use of solar energy systems for heating water and living space. Additional issues must be addressed when considering other forms of solar energy conversion, such as wind energy, ocean thermal gradients, and bioconversion systems.

The key policy question has been answered in the affirmative. Solar energy is important enough for government to encourage its use, but considerable doubt remains about the degree of involvement that is appropriate. Because most of the legal issues are within the jurisdiction of state and local governments, it is unlikely that we will witness any sweeping reforms. On the other hand, we should see a range of diverse and innovative approaches to the solution of these problems by thousands of governmental units acting as individual "laboratories."

The chief reason several centuries ago for securing a right to sunlight across neighboring land was to ensure interior lighting. With the advent of inexpensive energy sources, the concern shifted to the preservation of scenic vistas and other aesthetic considerations. We now are concerned once again with light for interior heating and other utilitarian purposes. The real obstacle probably is cultural inertia. Our social order evolved during an era of cheap land and cheap energy, and any system--economic, social, or ecological--changes slowly in the absence of outside forces.

Lawyers, technologists, architects, land-use planners, and others share an obligation to cooperate among themselves in conducting multidisciplinary assessments of how to develop a solar economy with a minimum of disruption. The barriers are not insurmountable, but we must learn to accomodate the requirements of technology and law before events preclude too many options and before too many policies become unresponsive to change. Our private and public welfare depends upon it.

Design for Energy Conservation

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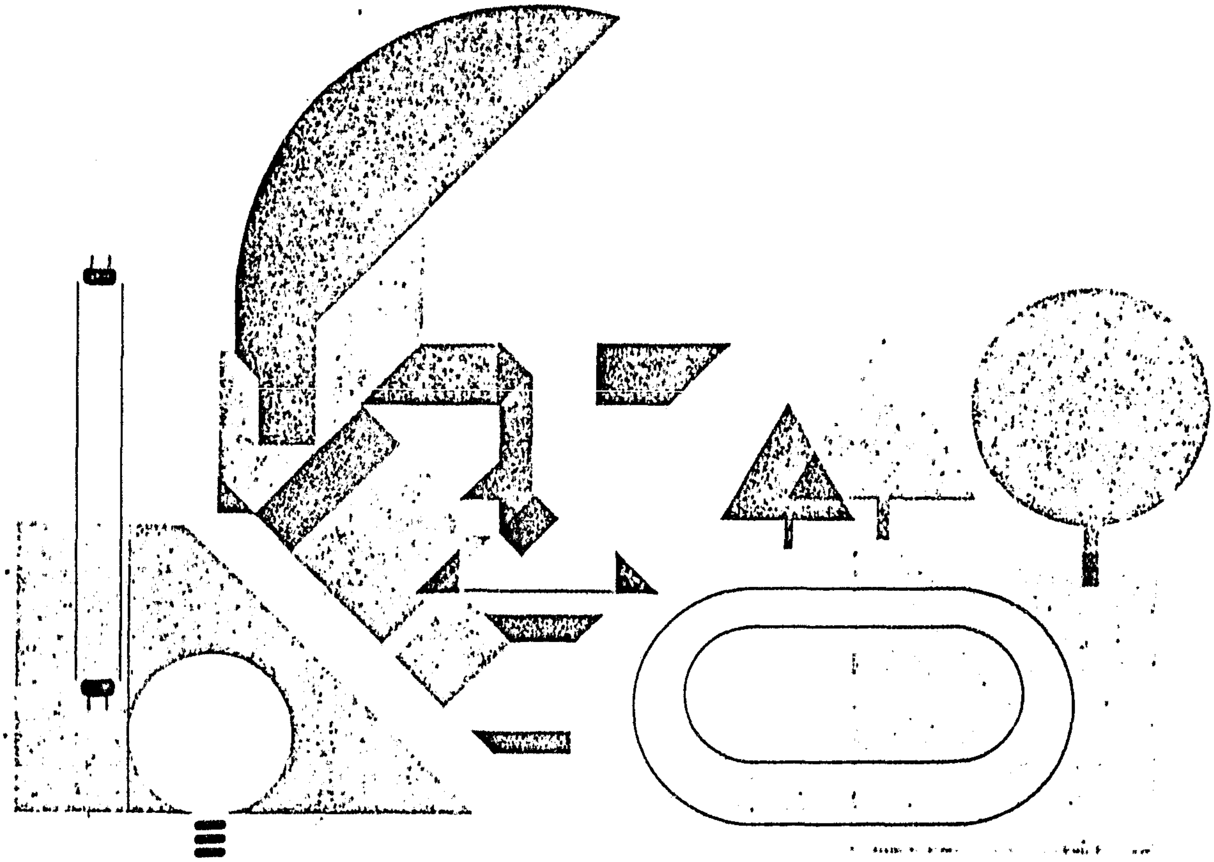
Health-Care Facilities

Bill J. Blair

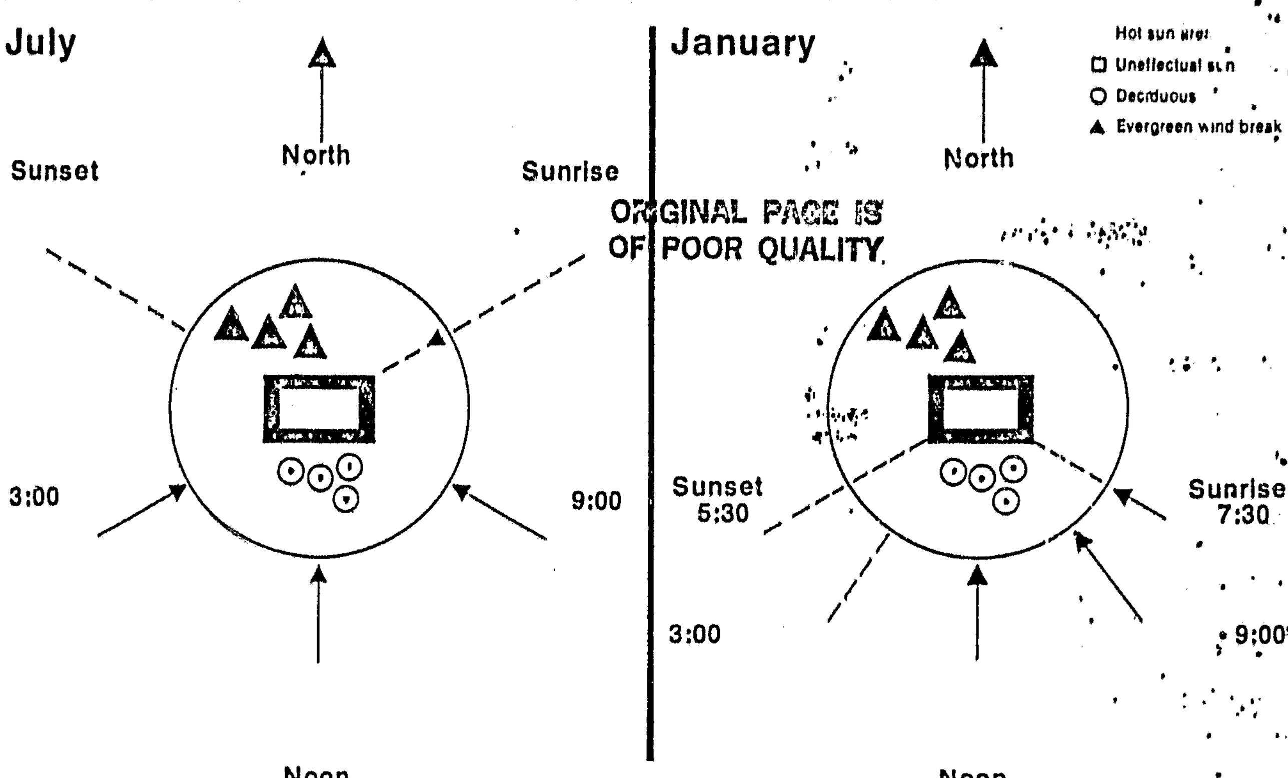


"Imagineering" is the provocative term a banking institution used to describe a project it financed. It is an equally appropriate word to describe how energy consumption and costs can be reduced for a major energy user — health-care facilities.

Energy sources, costs, and consumption quantities are significant issues in the health-care expense battle, and the traditional system-performance requirement rationale of the engineering profession can no longer be justified. Imaginative, innovative engineering is needed to devise new ways of controlling costs and conserving energy without sacrificing the comfort, safety, and professional services of these facilities. "Imagineered" architectural designs and mechanical/electrical systems can produce significant savings in the energy requirements of health-care facilities. Details deserving consideration are architectural design, landscaping, lighting, electrical and mechanical systems, and alternative energy sources including solar and cogeneration.

Architectural Design

Architectural design concepts that affect energy conservation efforts include thermal mass, building



40° Latitude

Fig. 1

orientation, subterranean or negative architecture, and space planning to allow for solar collectors.

Use of thick masonry exterior walls and/or adequate insulation of exterior walls augment heating and cooling efficiency during both winter and summer. The mass of the walls assists in offsetting the heating/cooling loads on a continual basis.

Building orientation with respect to the sun also is a significant energy conservation factor. Orientation to take advantage of the sun during the winter must be balanced with glare protection and heat reflection during the summer.

Subterranean or negative architecture has great potential for energy conservation, in combination with courtyards and lightwells to direct natural lighting into the interior and to provide suitable ventilation. Wholly or partially below-ground structures benefit from the natural insulation properties of the surrounding earth. Placement of glass areas and use of skylights and clerestories can prevent an undesirable, cavelike environment for patients, visitors, and health-care staff. In addition, subterranean designs can provide rooftop vehicle parking to mitigate the frequently severe problem of traffic and pedestrian circulation, especially in urban settings.

Application of solar slab/solar collector architectural designs could produce a patient wing with one wall as a solar slab, utilizing solar collectors as reflective umbrellas over space occupied by patients.

Landscaping

Generally considered for its esthetic enhancement rather than its energy-conservation potential is the landscaping of a health-care facility. Yet this aspect of design can reduce energy consumption considerably. The energy required to heat a building in a wind-swept setting is considerably greater than it would be if a landscaped wind screen blocked that wind. A well designed landscape can shield a structure from 85 percent of the winter wind, which in turn will provide a significant contribution to energy conservation.

Trees are important energy conservers, also. During the heat of summer, the temperature under a tree may be 25 degrees cooler than in the direct sun, due to evapo-transpiration heat loss and the resultant convection breezes. A mature tree generates an energy change equivalent to five 10,000 Btu air conditioners. One city has estimated that it would be required to spend more than $800,000 per day in energy costs to equal the cooling produced by its 200,000 trees during the summer.

Energy conservation landscaping is not complex. The basic concept is to block the hot summer sun and

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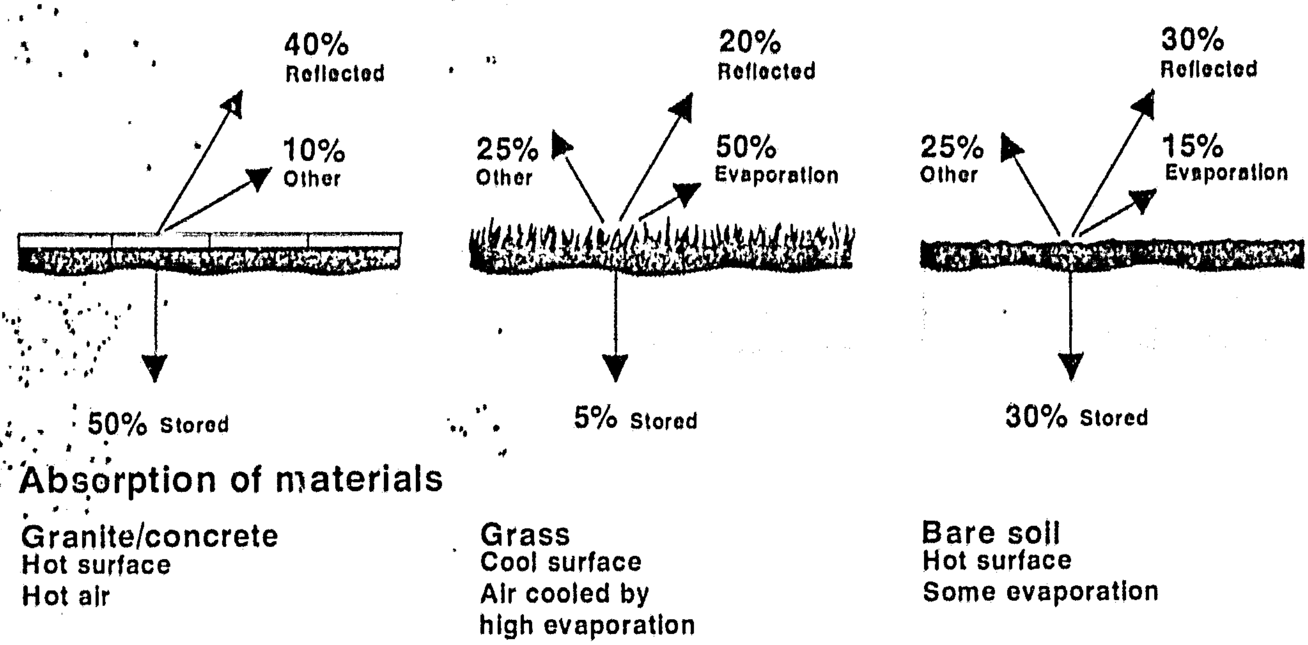


Fig. 2

channel summer breezes for cooling; in the winter, cold winds are blocked and the impact of the winter sun is maximized (Fig. 1). For example, deciduous plants in full leaf will provide protection from the summer sun on southern and western building facades. During winter, the sun will shine through or under leafless branches to warm walls and windows. Evergreens provide an effective winter wind screen, as well as a colorful, living environment.

Ground space temperatures vary considerably, depending upon the heat absorption properties of surface materials (Fig. 2). Grass and tree-covered space is cooler, obviously, than a paved parking lot. The initial savings from use of asphalt in hot climates become losses each year in the form of energy costs for air conditioning the surrounding buildings. Trees and groundcover would lower temperatures and save on energy consumption.

Grasses and shrubs near structures augment energy conservation. When used in conjunction with earth berms or mounds, this landscaping also provides privacy and sound control, opens or closes the view at the discretion of the designer, and channels wind currents (Fig. 3).

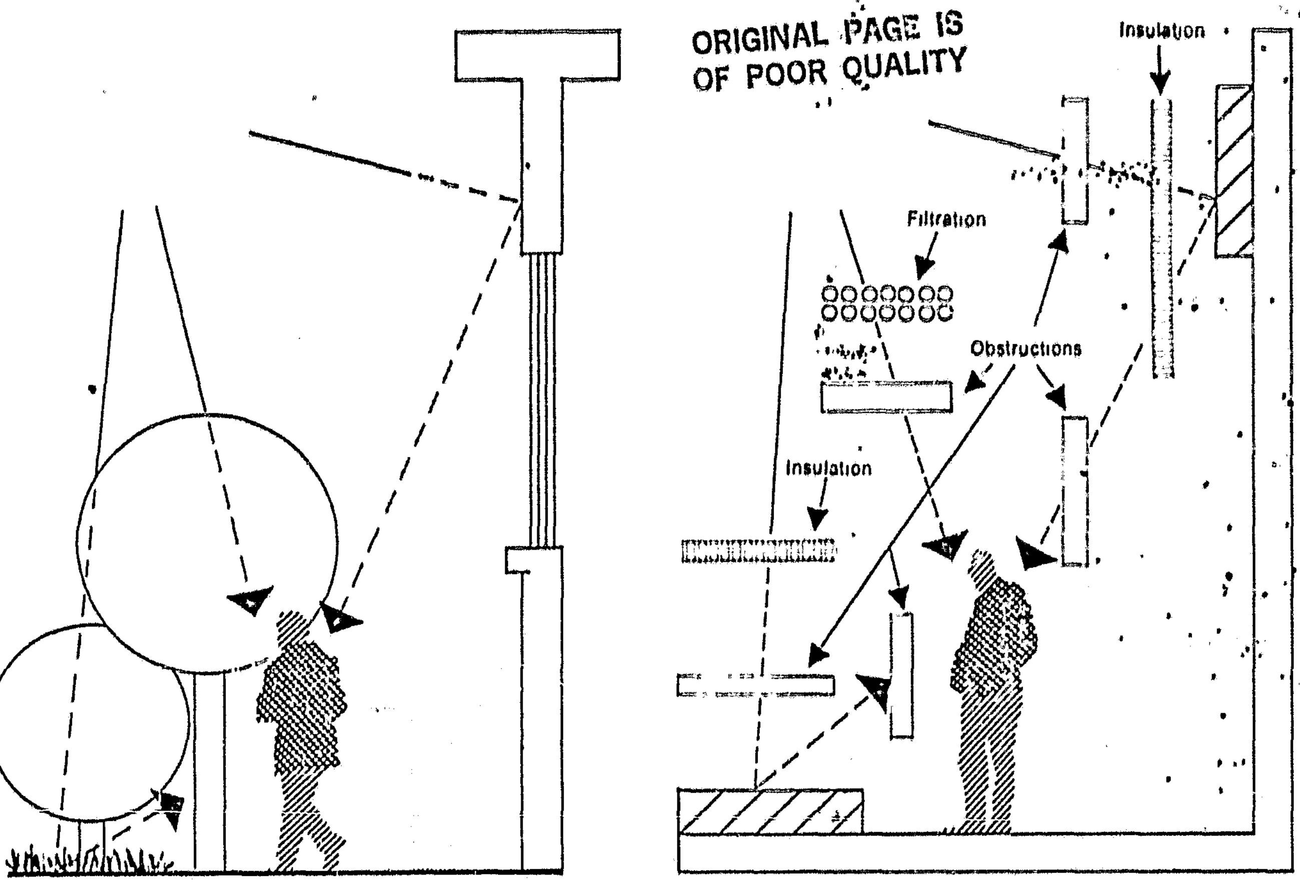
Judicious use of plant materials in the various climate zones, with careful consideration of solar and wind conditions, can produce a substantial savings in energy, as well as creating a beautiful, ever-changing environment.

Lighting Design

It is a challenge to design an energy-conscious lighting system for a health-care facility that fulfills functional requirements without wasting electricity. The variety of health-care related visual tasks and conditions creates a broad range of footcandle requirements: from 5 footcandles for bulk stores to 2500 footcandles for surgery.

Lighting technology and variations in light sources and lighting controls are promising areas for imaginative energy conservation in health-care applications. Greater efficiency has been achieved in lighting equipment, and commercialization of cost-effective electronic ballasts should bring about additional improvements.

The greatest potential for energy conservation in lighting systems without reducing the quality is in improved on/off control, lighting levels that correspond to specific task requirements, and daylighting to supplement the artificial illumination. The programmable controller offers a feasible means of energy conservation through switching control. Lighting system control functions may be implemented through telephone networks or standard control de-



Plants control solar radiation

Radiation reduction

Fig. 3

vices, and photoelectric, temperature, and time-function inputs are possible (Fig. 4).

Timing functions may be used for on/off control of lighting in offices, patients' rooms (during day and at night), special areas and exteriors, and in corridors. Photoelectric control may be applicable for the reduction of artificial light levels when daylight provides adequate illumination. The programmable control system can be utilized effectively to regulate illumination levels in open office spaces, such as accounting, personnel, and administrative reception areas.

Maximum utilization of daylight through architectural design and control of lighting levels throughout the facility can conserve energy. The potential energy savings are illustrated in Fig. 5.

Mechanical/Electrical Systems

The electric motors that are components of the electrical system also may offer a means of conserving energy. The emphasis in motor design traditionally has been on reliability and durability rather than energy needs. However, high efficiency motors are available in standard sizes, and the recently developed Wanlass controlled-torque motor signals technological advancement in the previously dormant area of motor design. Energy considerations in the electrical system portion of health-care facility design include the sizing of motors for intended functions, life-cycle costs, system power factors, and operational parameters.

Mechanical systems also offer substantial opportunities for energy conservation. Exhaust-air heat recovery is a major consideration. Rotating heat wheels, heat pipes, air-to-air heat exchangers, and run-around loops are methods for transferring heat from the exhaust-air stream to the outside air being drawn into the air-handling system. Some of these systems also are designed for humidity transfer.

Adiabatic cooling, a significant energy conserver, is feasible in regions where wet-bulb temperatures are low enough to permit spraying air streams with water, thus increasing humidity and lowering dry-bulb temperature without mechanical refrigeration.

Chilled-water system design presents a potential for energy conservation. While the chiller requires full flow through the evaporator, the chilled water coils in air-handling units do not, and it is generally economical to provide a primary loop through the

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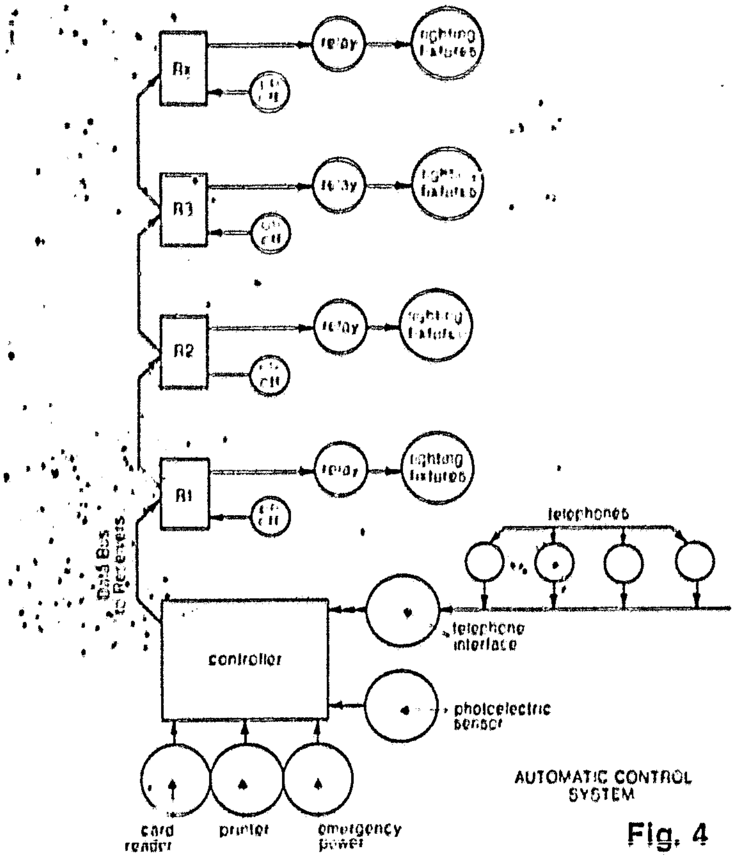

Fig. 4

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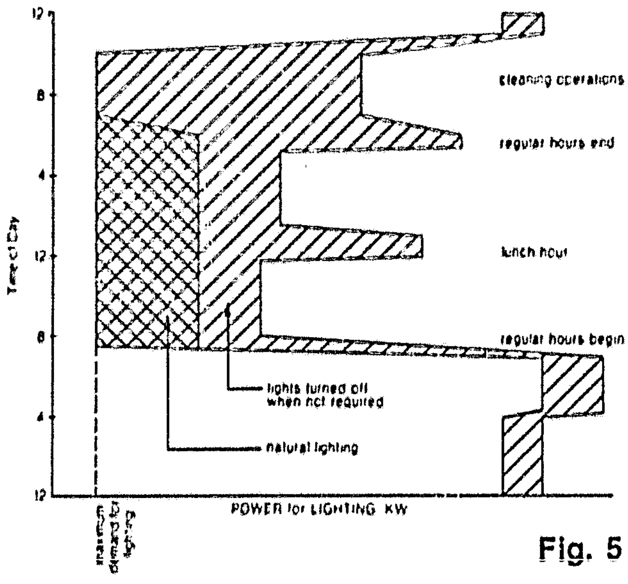

Fig. 5

chiller and a secondary loop with variable-speed or staged pumps for the air-handling units. The pumping horsepower savings are significant.

Use of two-speed fans for cooling towers enables operation at half speed, which is adequate for system requirements more than 70 percent of the necessary cooling hours.

Health-care facilities' requirements for large quantities of domestic hot water are a prime energy concern. Double-bundle condensers could provide most of the heat necessary for this purpose. This system reclaims chiller condenser heat by use of a second tube-bundle, through which cold domestic make-up water flows prior to entering the water heaters. Rejected heat is dissipated through the condenser water system and cooling towers.

Alternative Energy Sources

Solar energy offers tremendous potential, particularly as an energy source for domestic water heating. Most health-care facility designs offer sufficient roof area for solar-collector installation, and innovative architectural designs featuring the use of solar energy can be adapted to the health-care field.

Ultimately there will be greater use of windmills to drive generators, a concept allied to solar energy because of wind's dependence upon solar activity on the earth's surface. Wind has been used for centuries to pump water and grind grain, and it also can be harnessed to supplement existing electrical generation techniques.

Cogeneration is a final consideration that may be applied advantageously. Also termed total energy systems, cogeneration enables the health-care facility to generate its own power and to recover heat from the generating process to produce steam for kitchen/sterilizer use and heating/cooling purposes. Fuel utilization efficiency is increased substantially in these systems (fuel-to-load efficiencies of 70 percent are not uncommon).

Energy conservation is no longer just the battle cry of dissident environmentalists and vote-seeking politicians. The doubled and tripled utility bills and the escalating costs of providing as well as receiving health care have created the demand for judicious use of energy that has been needed for many years.

The technology and equipment are available to substantially decrease energy consumption levels. Design professionals must supply the "imagineering" that can lead to significant energy conservation in health-care facilities. ▲▲

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Industrial buildings serve a wide variety of functions from assembly operations to foundries. Each type of building has unique opportunities for energy conservation because of the differences in the mechanical services required for the process equipment. Industrial buildings are typically single-story structures with the roof representing the greater portion of the surface area. The building height generally is dictated by the process equipment and material handling space requirements.

Design of industrial buildings for energy conservation can be achieved through an integrated systems approach to the building construction, services, process, and environmental equipment. This requires a great deal of coordination between the owner and the consulting engineer. The primary problem encountered is the dependence on the availability and timing of information regarding process equipment. Often the owner is evaluating a number of alternative processes, each of which may have different characteristics with respect to opportunities for energy conservation.

Concept Studies

A conservation concept study should be prepared as part of the preliminary design phase of the project. It should include sufficient description, diagrams, and economic analysis to make a decision to accept or reject the concept, but it need not be complicated to be effective. The engineer must be observant to identify energy conservation opportunities and be innovative in developing the design concept. The rationale for acceptance or rejection of specific conservation opportunities can be based on calculation or experienced engineering judgment, as deemed appropriate with respect to the magnitude of expected savings.

Design time for industrial buildings will vary significantly between projects and clients. The energy conservation concept report format also will vary depending on the design time frame and the needs of the client. Some clients prefer a complete formal report where all concepts can be reviewed prior to authorization to proceed with design. Other clients prefer to review the concepts on an as developed basis to expedite design.

The organization for energy conservation design in industrial buildings is basically a five step process:

- Identify the energy conservation opportunities (ECOs).
- Develop the design concepts.
- Screen alternatives to select ECOs for further evaluation.
- Estimate the return on investment.
- Select ECOs to be implemented.

Identification of energy conservation opportunities is the only one of the five steps that needs further definition to address industrial buildings specifically. An organized approach to identifying the ECOs involves consideration for those services and equipment which typically have a significant impact on the energy consumed. It includes these procedures:

- Review process equipment for ECOs related to waste heat recovery or exhaust recirculation.
- Determine process exhaust requirements and identify equipment to be provided with enclosures.
- Determine occupancy schedule and definition of production areas for zone control of mechanical systems and lighting.
- Develop schematics of alternative mechanical systems and control for support of process and building services.
- Review mechanical systems schematics for: more efficient energy sources; potential secondary uses of energy; ability to operate efficiently at part load; adequate backup for waste heat recovery sources; and ability to maintain make-up air at a minimum to compensate for process exhaust and provide for worker health and reasonable comfort.

Once ECOs are identified, evaluation can proceed as previously outlined. Passive measures for energy conservation common to all building types, such as insulation for building surfaces and piping, also should be evaluated for return on investment.

Major Areas for Energy Conservation

Mechanical and electrical systems must be selected to satisfy the building functional requirements while being conservative in energy consumption and attractive with respect to annual owing and operating cost. The goal for most owners is to reduce annual owning and operating cost, not merely to save energy at any expense. The exception is when availability of a fuel source is threatened by a curtailment.

The greatest energy savings for industrial buildings result from coordinating the operation of me-

chanical systems and lighting with building occupancy, controlling the amount of outside air that is introduced to the facility by air handlers and infiltration, providing for efficient off-peak operation, and by passive measures such as adequate building and piping insulation. Systems also must be designed to facilitate maintenance. Preventive maintenance is important to assure long-term efficient operations.

Heating make-up air supplied by air handlers to provide ventilation air and replace air volumes exhausted from process equipment accounts for a major portion of the energy consumed in support of an industrial facility. There are two alternatives for reducing the amount of primary energy expended to heat make-up air. One is to reduce the amount of make-up air, the other is to employ heat recovery to heat the make-up air. Reduction of make-up air must be accompanied by an equal reduction in process exhaust. Heating make-up air with waste heat recovery is dependent on the availability of a waste heat source. Initial emphasis should be placed on the reduction of exhaust air quantities.

Automated processes often can be provided with enclosures that reduce the amount of air needed to prevent contaminant emissions to the work area. Ideally, untempered outside air can be provided at the enclosure so that heated room air is not exhausted. Equipment enclosures often provide secondary benefits such as noise reduction, and minimize uncontrolled heat dissipation to the space, which may allow reduced summer ventilation.

When a process cannot be enclosed, air curtains should be considered to isolate contaminants and process heat rejection. Heat can be vented by gravity above the area contained by the air curtain or recovered if economically feasible. If a process cannot be enclosed or air curtains are not applicable, then the process exhaust requirement must be reduced by maximizing the efficiency of contaminant collection by providing properly designed hoods, using unheated compensating air, or providing filtration to allow recirculation of exhaust air to the work area.

Recirculation of process exhaust air is not applicable to all processes. The nature of the contaminant and particle size distribution must be considered when selecting a collection device appropriate for recirculating the exhaust air to the work area. Particle size distribution can be determined by sampling emissions from an operating process. Often emissions abatement equipment manufacturers can provide typical data based on previous experience. High efficiency filters or electrostatic precipitators can be very effective in removing particulate emissions. Pollutants such as welding fumes should be collected at the source before they expand and contaminate the general atmosphere of the work area.

Collecting contaminants at the source minimizes the volume of the particulate abatement equipment.

Maximizing Waste Heat Recovery

Sources of waste heat are readily identifiable. Hot process exhaust released outside the plant and cooling water energy dissipated with a cooling tower are common losses. Current technology is available to extract heat from exhaust gases either by air-to-air or air-to-liquid heat exchangers. Hot process cooling water return sometimes can be used directly in hot water coils for ventilation air heating. Often, the temperature is too low to be used directly and a heat pump must be added to extract the usable heat energy. Heat recovery from low energy sources may be uneconomical. Each application must be evaluated in terms of return on investment.

Process systems and equipment should be designed to be inherently energy efficient, such as heat treat ovens that use waste heat to preheat combustion air. Waste heat should be recovered as close to the source as possible to avoid thermal energy dilution. The economics of heat recovery improve as the temperature of the waste heat increases and the available thermal energy per pound of transporting medium increases.

High energy, continuous operating sources are the most desirable for waste heat recovery. However, high energy waste heat sources often are a great distance from the point where the energy can be utilized. Examples of waste heat sources that generally are remote from a point of utilization are air compressors, electrical substations, and miscellaneous processes scattered throughout the manufacturing area. The combined waste heat energy of miscellaneous processes may be significant but uneconomical to recover on an individual basis.

Attention must be given to the overall thermal efficiency of systems in support of the process equipment. Secondary use of primary energy should

be provided for wherever possible. Steam supplied to bake ovens is a prime example of an opportunity to use secondary thermal energy without having to use heat recovery devices. Steam supplied to bake ovens is typically 125 to 150 psig to maintain the high temperatures required by the process. The high pressure condensate can be flashed to low pressure steam which can be used to supply the heating and ventilating units or to preheat process make-up water. Condensate should be returned to the boiler unless contaminated in some way by the process.

Systems Control for Energy Conservation

The major emphasis in design and control of systems or equipment for energy conservation must be placed on efficient operation at partial load. Systems and equipment are designed to accommodate maximum load conditions, which may include future loads; in practice, most operate at varying conditions of partial load. Operation over the design range may cycle anywhere from a daily to seasonal basis.

Design considerations for off-peak operation include the use of variable speed drives, primary and secondary pumping systems with bridge differential pressure control, and multiple equipment of varying capacity in parallel, all of which provide for efficient operation at reduced load. The choice of the specific method must be consistent with the operating requirements of the system. Variable capacity operation is suitable if the whole system loads and unloads evenly. However, primary-secondary pumping may be more suited to a system having components which peak at random.

Selective start-up and shutdown control can be effective in reducing demand and consumption. Staggered start-up of electrical equipment reduces demand charges. Controlled start-up of steam equipment may preclude having to bring additional boiler capacity on line for short periods of time. The systems control must be coordinated with the production areas so support systems, lighting, and equipment can be turned off when individual production areas are not in operation. Control action can be manual or performed by automatic central control systems of varying sophistication. Automatic control is preferred over manual since it assures that the control functions will be accomplished and conducted in proper sequence. Provisions also should be made to implement load shedding to reduce energy demand and consumption.

Automatic control to achieve positive shutoff of some services, such as steam, is essential to prevent energy waste. Make-up air heating often is controlled by coil face and by-pass dampers. Face and by-pass dampers do not adequately prevent the heating of make-up air during the nonheating season. An automatic steam shutoff valve will prevent energy waste and improve worker comfort.

Building Construction

Industrial building design and construction features generally are suited to the needs of the manufacturing process and the logistics of shipping and receiving raw materials and finished goods. The control of surface openings and the provision of surface insulation are the major factors in energy conservation. Glazing usually is minimized on industrial buildings because of maintenance considerations.

Adequate roof insulation allows the stratification of heat in the truss space where it can be recovered or recirculated to the occupied area. Roof and wall insulation thickness must be determined by economic evaluation. The economic thickness is a function of the temperatures to be maintained inside the building, the geographic location of the facility, and the unit costs of insulation and energy.

Control of larger openings, such as truck dock and railroad doors, is essential to limit the infiltration of outside air. Single openings often can be provided with air curtains, while multiple openings can be protected with a truck dock vestibule.

Designing for energy conservation in industrial buildings requires an organized, systems approach to take advantage of the multiple opportunities presented by the plant's processes and equipment. These may include secondary uses of energy, such as waste heat; the ability to operate efficiently at partial load; and ways to maintain make-up air at an acceptable level without undue expense or energy usage. Insulation, fenestration, and overall building construction also lend themselves to energy conservation opportunities. ▲▲

Mr. Harrison is manager, Energy Conservation/Air Pollution Control, at Giffels Associates, Inc., Southfield, MI.

Solar Power On the Farm

by William S. Sullins
Assistant Extension Editor
Kansas State University

Using solar energy on the farm was only an idea in the early 1970s. Today it is an idea whose time has come. Solar power is here, helping to produce meat for the dinner table.

Twelve Kansas livestock producers are using solar power to heat swine farrowing houses. By year's end, the number will be at least 16.

"A producer investing in a solar collector-storage system similar to an experimental unit located here (Kansas State University) can recover his investment in 7 years," claims James P. (Pat) Murphy, Extension agricultural engineer in structures and environment. "Many traditional farm structures are built with the hope that the investment is returned in 10 years."

Murphy is the conduit through which research information collected at the experimental facility, built 4 years ago, is transmitted for actual on-farm use. Under a combination Department of Energy (DOE) and USDA-SEA grant, Murphy spends a third of his time working with farmers interested in solar-heated hog facilities.

Once a producer decides to go that route, he may get his plans and instructions from Murphy. And the specialist throws in some practical advice to help get the project off the table.

The plans basically reflect experimental work done at K-State by professor Charles Spillman, Department of Agricultural Engineering. Animal science professor Robert H. Hines and research assistant Victor Robbins aided Spillman in the project.

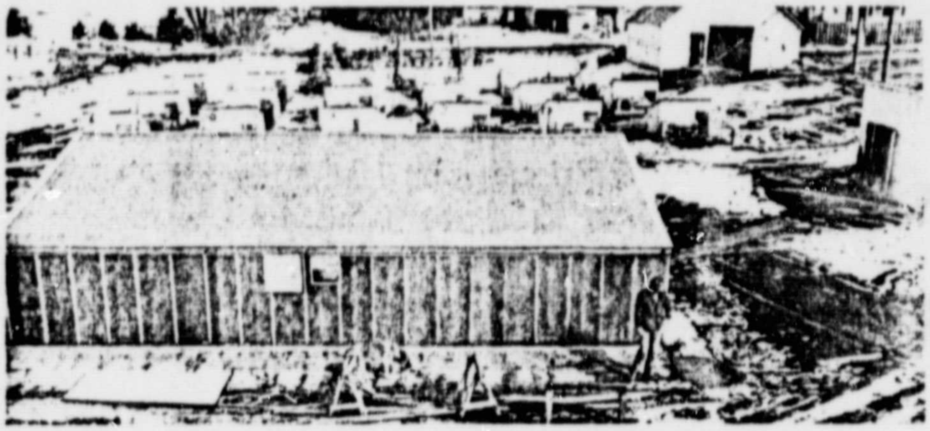
Spillman built the experimental 8- by 50-foot solar collector-storage unit on the south wall of the farrowing house at the university's swine research center. Partial funding was provided by the Economic Resource Development Agency (ERDA).

The idea is to use the solar wall to preheat ventilating air in the hog house. In winter, fresh air entering a livestock building must be heated to the temperature in the confined space. In Kansas, where high winds may combine with cold temperatures to send the wind chill index plummeting to several degrees below zero, energy required to obtain that goal can be excessive. Most producers use LP gas or electricity to heat the space.

Solar energy is ideal in this case, Spillman points out, because a system to preheat the ventilating air can use energy of much lower quality, as heat of any kind in winter reduces the amount of conventional energy used.

Another appealing feature of solar power is that producers don't have to build a new structure to take advantage of the sun—a wall can be added to an existing building, as was the case at K-State.

The main features of the solar wall, which provide a net collecting area of 380 square feet, are a stack of solid concrete blocks (6 by 8 by 16 inches) painted black with openings from front to back, and a

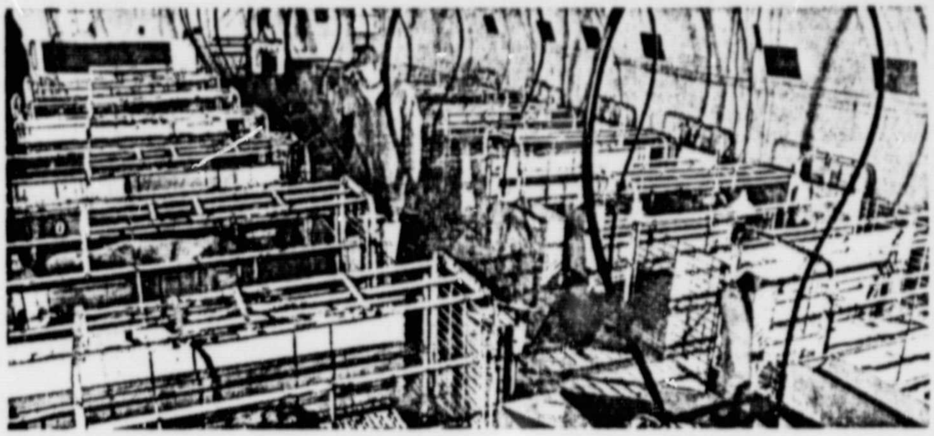


This view of a solar-powered farrowing house shows isolettes in the background—individual quarters for a single brood sow and baby pigs. The isolettes will eventually be phased out, thus saving labor and energy costs (0279W218-4).

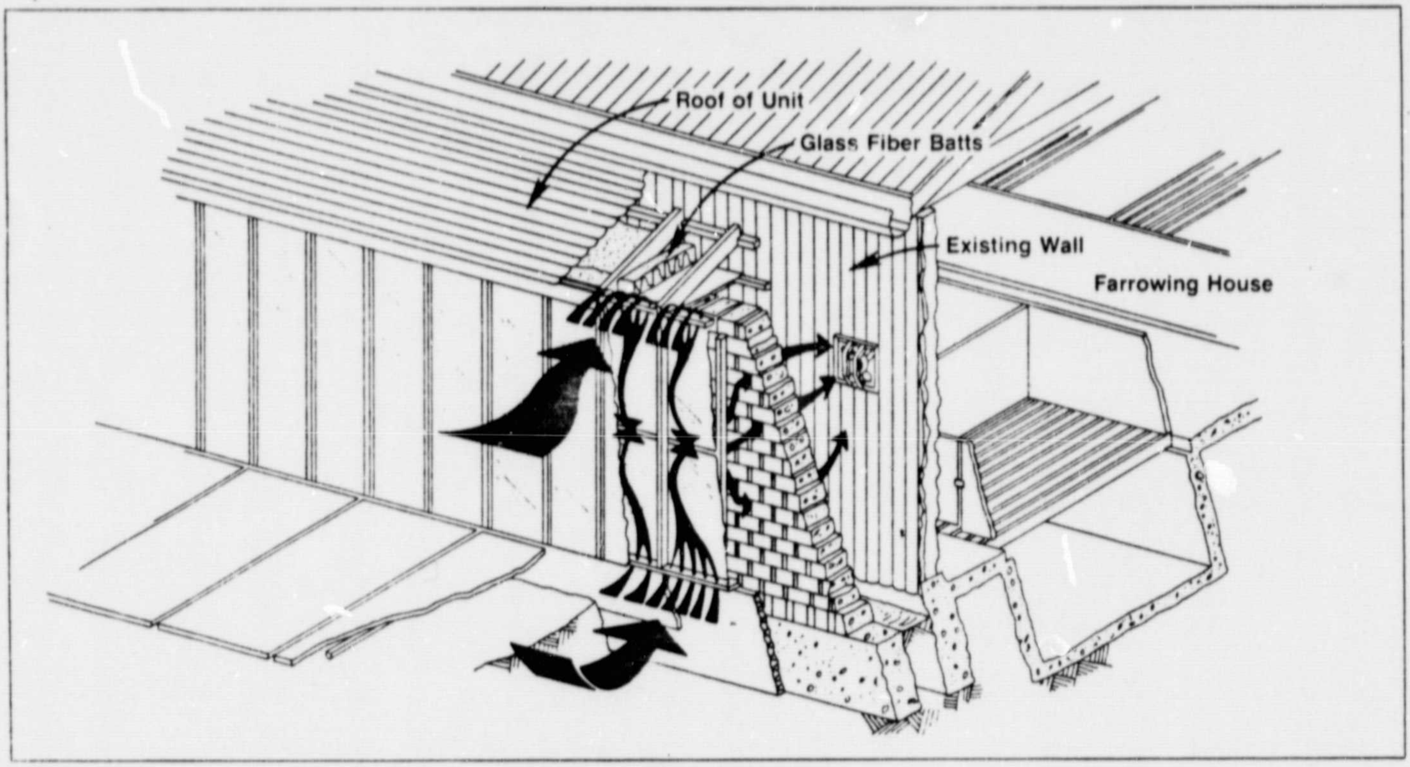
ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

Charles Spillman (left) and James P. Murphy discuss possible alternatives for improving the performance of solar units being used by a pork producer (0279W213-26A).

Arlan Benteman is one of 12 Kansas livestock producers using solar power to heat swine farrowing houses. He should recover his initial investment within 7 years (0279W220-22A).



This solar energy collection and storage wall supplies natural heat for Kansas State's farrowing house. Arrows show the path of air as it is heated on its way to the ventilating fan (PN-4189).



double transparent plastic cover on a frame that allows ventilating air to pass between the covers as it enters the system.

Moving the air through the space between the covers allows the air to pick up some of the heat that would otherwise be lost. The air removes heat from the south side of the blocks first and cools the surface to further reduce heat loss from the storage.

Inside, a centrifugal fan connected to a duct system moves the air to the furnace in the farrowing house.

Spillman says the solar energy collected and used January through March one year was equal to burning 335 gallons of propane; from April 1 through June, savings equaled 170 gallons.

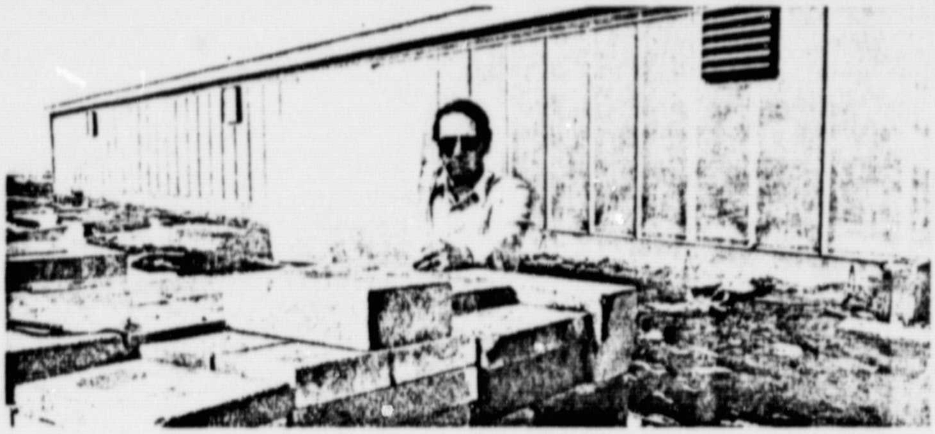
With farrowing house temperatures maintained at 60° to 65° F., Spillman estimates the equivalent of 1 gallon of propane is saved for each square foot of collector for Kansas conditions. Savings would vary depending on location.

The scientist believes the basic concept of the solar energy collector-storage system for preheating ventilating air will become a viable economic alternative as energy becomes less available and more expensive.

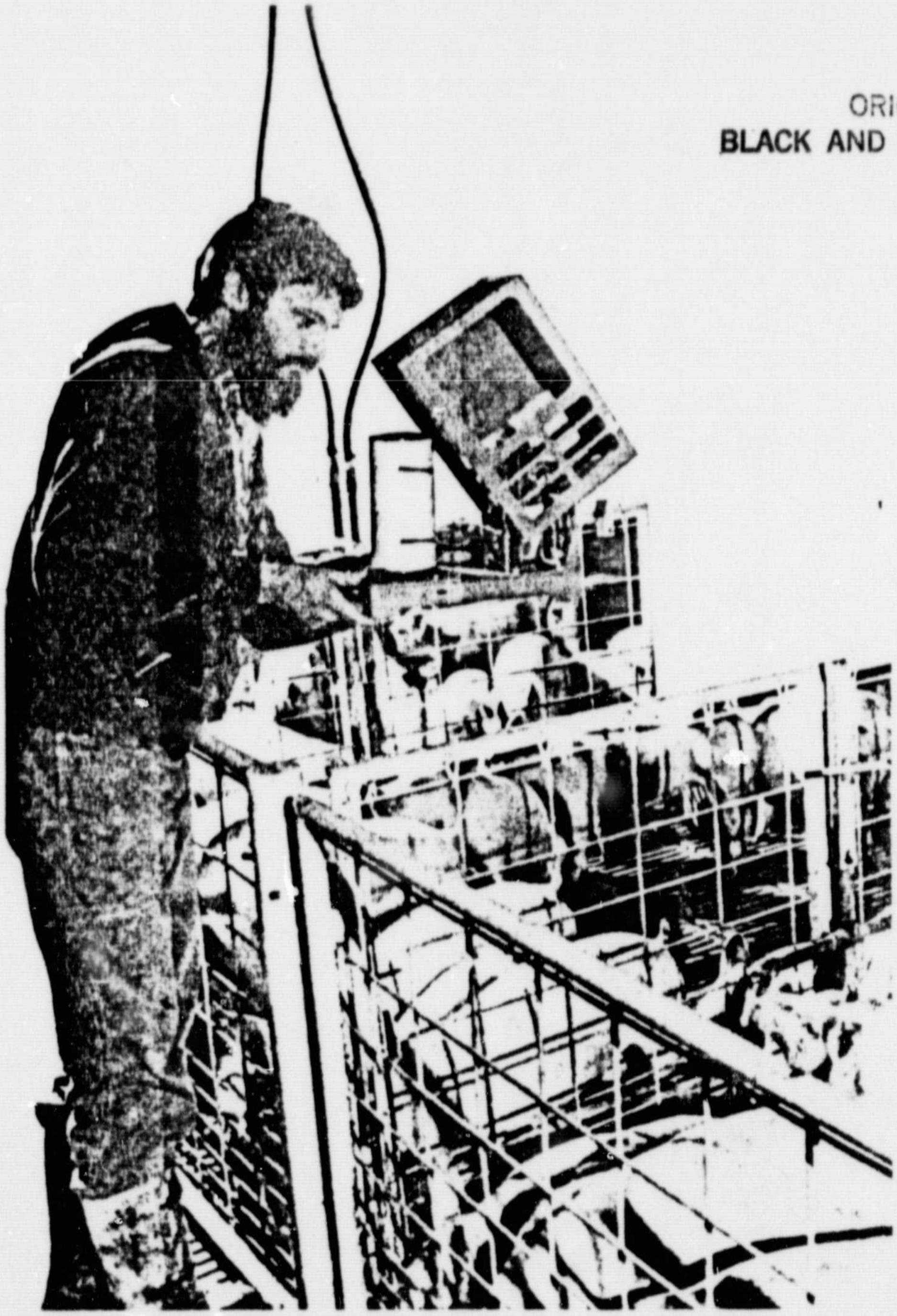
"We plan to continue research and hopefully refine the system to make it even more efficient," he said.

As for cost, Murphy said his experience with farmers indicates that a solar wall for preheating ventilating air in a farrowing house can be built for $7.50 per square foot of collecting space. About $4 of that amount is labor.

Plans and operating instructions for the collecting system are available for $3 per set from Murphy at Extension Agricultural Engineering, Seaton Hall, Kansas State University, Manhattan, Kan. 66506.□



Dale Keesecker's solar collectors were built from concrete blocks and resin reinforced fiberglass panels. All materials needed to build a solar-powered farrowing house are readily available to producers through building contractors, lumberyards, and solar energy vendors (0279W217-34).



Alan Johnson, assistant research engineer, keeps a watchful eye on monitoring equipment in the nursery on Dale Keesecker's farm in Washington, Kansas (0279W217-25).

Farmer dries corn with solar energy and Danish aeration system

■ AL BOYD and his father Lyle, Argenta, Ill., know the value of solar energy in grain drying.

These Macon county farmers not only use solar-heated air to dry corn in their 50,000-bu. flat-storage building but also added a Danish aeration system that uses forced air to unload the building.

"Solar compares favorably with the cost of elevator drying," Al Boyd says. "Solar grain drying is the most energy-efficient means available. In 1976 we used 1224 BTU (British thermal units) to remove a pound of water from the corn. In 1978 we used only 697 BTU."

Those BTU figures are the amount of energy Boyd purchased. For comparison, University of Illinois ag engineers say a high-speed gas dryer uses 2000 to 3000 BTU to remove a pound of water.

He quickly points out that during the 1976 drying season he dried corn using natural, not solar-heated, air. He didn't install the fiberglass on the 4000-sq.-ft. suspended-plate collector on the south wall of the 40x100-ft. building until 1977.

"The fiberglass resulted in a 40% decrease in the energy requirements to remove each point of moisture," he says. The kilowatt hours (kwh) needed to remove each point of moisture dropped from 0.25 kwh per point in 1976 to 0.153 kwh in 1977 and to 0.142 kwh in 1978.

Boyd, who holds a doctorate in mathematics, has kept other records to show the efficiency of the dryer. "The data are accurate," he emphasizes. "We weighed and moisture-tested each load and metered the electrical power."

In 1978 he dried 36,760 bu. of corn from an average of 21.46% moisture to 13.56%. He started harvesting corn at more than 30% moisture and stored several thousand bushels at more than 25% moisture. The per-bushel drying cost was 5.46¢, or 0.69¢ per point of moisture.

Data from the 1978 drying season closely parallel the results from 1977. In 1977 he dried 38,620 bu. of corn from 17.42% to 14.8% moisture. Cost per bushel was 2.17¢, or 0.83¢ per point.

"When you compare energy costs, only gas drying is competitive with solar drying," Boyd continues. "If you pay 36¢ per gallon of propane that contains 90,000 BTU, the 2000 to 3000 BTU a gas dryer uses to remove a pound of water costs between 0.8¢ and 1.2¢.

"If it takes 2500 BTU to remove a pound of water, the cost would be about 1¢. This is the same cost as using solar drying in 1978. The question seems to be which form of energy – electricity or gas – will increase in cost more rapidly," he says.

Grain distribution

Boyd's method of grain distribution as well as that of aeration and unloading make his so-

Prairie Farmer - October 20, 1979

lar building unique.

Grain enters the west end of the building on a conveyor belt from a cleaning tower. The variable-speed conveyor belt near the ceiling moves the grain from west to east while a V-plow designed and installed by Boyd moves along the belt unloading the grain.

Boyd can adjust conveyor belt speed from 5 to 20 ft. per second. "You need the 20-ft.-per-second speed to throw the grain to the outside of the bin," he explains.

With this system, Boyd unloads grain in the center of the bin until he has a ridge of grain the length of the building. He then increases the speed of the belt, which gradually spreads the grain toward the bin walls. He says the impact of the grain falling is equivalent to a 4-ft. drop. "That won't damage much grain," he says.

Danish aeration system

In 1978 Boyd installed an aeration system made by Palle Westerby, a Danish firm. It's the only one of its type in North America. Boyd uses three 20-hp fans to pull air from the top of the collector into a collection chamber on the south wall. These fans force the heated air through three 36-in. culverts to a main duct that runs the length of the building.

Radiating from each side of the main duct are 30 laterals that reach from the center of the building to the outside bin walls. The laterals are spaced one meter apart or slightly more than one yard. The main duct carries heated air to the laterals, houses the center drag for grain unloading, and contains the control doors and levers for each lateral.

Before installing the Danish system, Boyd had aerated the

INSIDE the main duct Boyd opens a door that allows air to enter one of the 60 laterals. Levers near the doors open gates to let corn enter the drag.

corn with seven 18-in.-diameter perforated metal tubes from each of the 20-hp fans. He says the tubes did an adequate job of aeration.

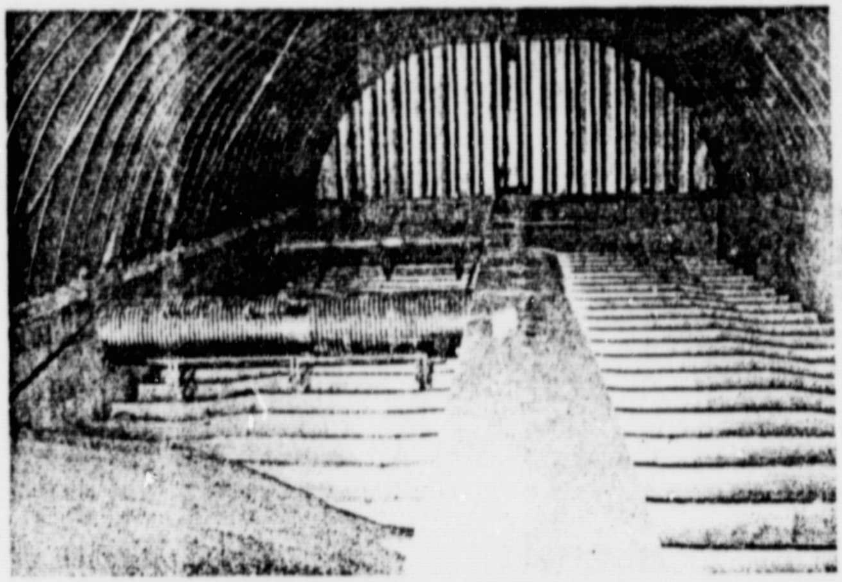
"But we had to move the tubes to unload the building," he notes. "We'd unload the building by backing a transport auger into the grain. You could unload it fast enough but it took three or four people.

"This Danish system is self-unloading. It uses an additional 0.1¢ per bushel in electrical power but saves 0.7¢ per bushel in labor costs.

"When gravity fails, air forces grain into the drag. The system saves the labor of three men."

To unload corn from flat storage, Boyd goes into the main duct and opens doors allowing grain to flow into the floor-level drag. When corn won't gravity-feed into the drag, he closes all but the rear eight laterals and turns on the fans. The air is forced out the open laterals, moves behind the corn, and pushes it to the center drag.

Boyd says the system leaves about a half-bushel of corn between each pair of laterals.



THIS VIEW of the interior of the building was shot from atop the main duct. On the left you can see two of the three 36-in. culverts that carry solar-heated air from the solar collector to the main duct. Also note the laterals from the main duct to the outside wall.

AL BOYD opens access door to the main duct of his aeration and grain-unloading system. This main duct runs the length of the building and houses the center drag and levers for laterals.

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NEWS

U.S. DEPARTMENT OF AGRICULTURE

Advance for Release at 6:30 a.m. EDT, Monday, Oct. 15, 1979

PORTABLE SOLAR HEATER DEMONSTRATED AT AGRICULTURE

WASHINGTON, Oct. 15--A portable solar heating unit designed to provide low-cost energy for a variety of farm uses was introduced to the public in a "hands on" demonstration here today.

Members of Congress, government and industry officials, representatives of farm and environmental groups and interested bystanders took turns assembling the unit on the lawn of the U.S. Department of Agriculture.

Agriculture Secretary Bob Bergland said the portable solar collector was a "potential break-through in helping the farmers and ranchers of this country reduce the growing burden of petroleum and propane fuel costs."

"If the final tests, which are due before the end of this year, are successful, we will have taken a giant step toward our goal of energy self-sufficiency on the farm by 1990," Bergland said. "This solar collector can be moved from place to place on the farm for use in such operations as drying grain, heating a farrowing house or providing heat for young chickens -- all at low cost."

The heater also can be used to warm the farm residence when not used for other purposes. The final testing is to be conducted in Arizona later this month. If the final results are as expected, plans and specifications for manufacture are expected to be available by January 1980. The cost of materials is estimated at about $2,500.

- more -

The unit can be marketed in several ways. Farmers eligible for Farmers Home Administration (FmHA) loans could finance the heater through a farm improvement loan. Contractors could be licensed to do the installation, or plans could be made available to persons who want to do their own installation.

Bergland said the solar unit also would be eligible for farm facility loans administered by the Agricultural Stabilization and Conservation Service (ASCS) for the primary purpose of grain drying. Loans for solar grain drying systems have been available to farmers through ASCS county offices since last May 25.

The solar heater was developed for FmHA by Douglas Wilke, a Glen Head, N.Y., engineer and architect, in cooperation with Bethlehem Steel Corporation of Bethlehem, Pa.

"This unique blend of small business, big business and government proves that this course of action can work and work well," Bergland said. "It is directly in keeping with President Carter's stated policy of merging private and public efforts whenever and wherever possible to help solve the energy problems we face today and anticipate tomorrow."

The portable unit is derived from a stationary model being tested on FmHA-financed homes in three states -- Maine, Virginia and New Mexico. Installations are being made on test homes in the three additional states of Illinois, Oklahoma and North Dakota.

If test-proven, the collectors will be offered as an option on FmHA-financed rural homes where they also can provide heat for hot water at no additional operating costs. FmHA finances an average of almost 150,000 rural housing units a year. Many of them could be fitted with the solar heating unit which could be financed through the mortgage loan.

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Advance for Release at 6:30 a.m. EDT, Monday, Oct. 15, 1979

4009 USDA 2392-79

PREPARED FOR:

NASA/IITRI
MANUFACTURING APPLICATIONS TEAM

10 W. 35 ST. CHICAGO, ILL. 60616

DOE/NASA SIMS PROTOTYPE SOLAR SYSTEM #4

PART 2 MODULAR MANUFACTURING COST ESTIMATE

ATTENTION: MR. EDMUND R. BANGS, DIRECTOR
NASA MANUFACTURING APPLICATIONS TEAM

PREPARED BY: MR. J. W. SIEGER, PRESIDENT
THE COOK COMPANY
LA GRANGE, ILLINOIS 60525
(312) 354-1315

The Cook Company

GENERAL CONTRACTORS

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1. Introduction

1.1 Costing Basis

The solar system construction cost study contained herein is based on actual unit cost figures used in estimating both residential and commercial projects in the Chicago Metropolitan area.

1.2 Design and Zoning Considerations

All design construction, zoning and building codes for the Chicago Metropolitan residential area have been taken into consideration in obtaining the final installed cost. Actual installation can deviate from estimated costs, due to specific local town or village codes, set-back requirements and architectural appearance requirements.

1.3 Scope of Study

The enclosed cost study does not represent a proposal to build and install a solar heating unit. The estimate is solely for the purpose of evaluating the system's cost when manufacturing the system in a modular fashion and shipping the modules to the construction site for assembly. The estimate is based on system quantities of 1 and 10,000.

2. Discussion

2.1 Portability

The SIMS solar system has been presented as a self-contained, portable solar system. It appears that a more practical product would be presented as a pre-packaged system, with final fabrication at the project site since the present level of system portability is limited.

2.2 Design and Construction

The SIMS solar system #4 operationally appears to be a typical solar system, without any new or unique features. It is presented to the end user as a complete prefabricated unit. In some instances the materials of construction are far more sophisticated than required to meet most building codes.

2.3 Zoning

The Chicago residential metropolitan area is very strict on the use of out-buildings or sheds. The collector building would most likely be considered an out-building, and, therefore, its use restricted if another out-building (i.e., detached garage) was anticipated.

2.4 Building Codes

To be acceptable in the City of Chicago, or many suburban areas, the entire system, if installed as a prefabricated unit, would most likely require a U.L. listing and label.

2.5 Freeze Protection

The system as designed incorporates a thermal bleed system to prevent freezing below certain temperatures. The system is inadequate for Chicago, or more Northern areas of the country.

2.6 Adapting to Existing Systems

It is necessary to locate the collector building facing South for efficiency. However, the following conditions could prevent this location:

- Lot line restrictions on the South Side of the existing building.
- Existing heating source (i.e., gas fired furnace) might be on the opposite side of the house.
- Bulky connections (photo #3 and #4) would be impossible to make or create interference with existing use of connection area.

3. Analytical Approach

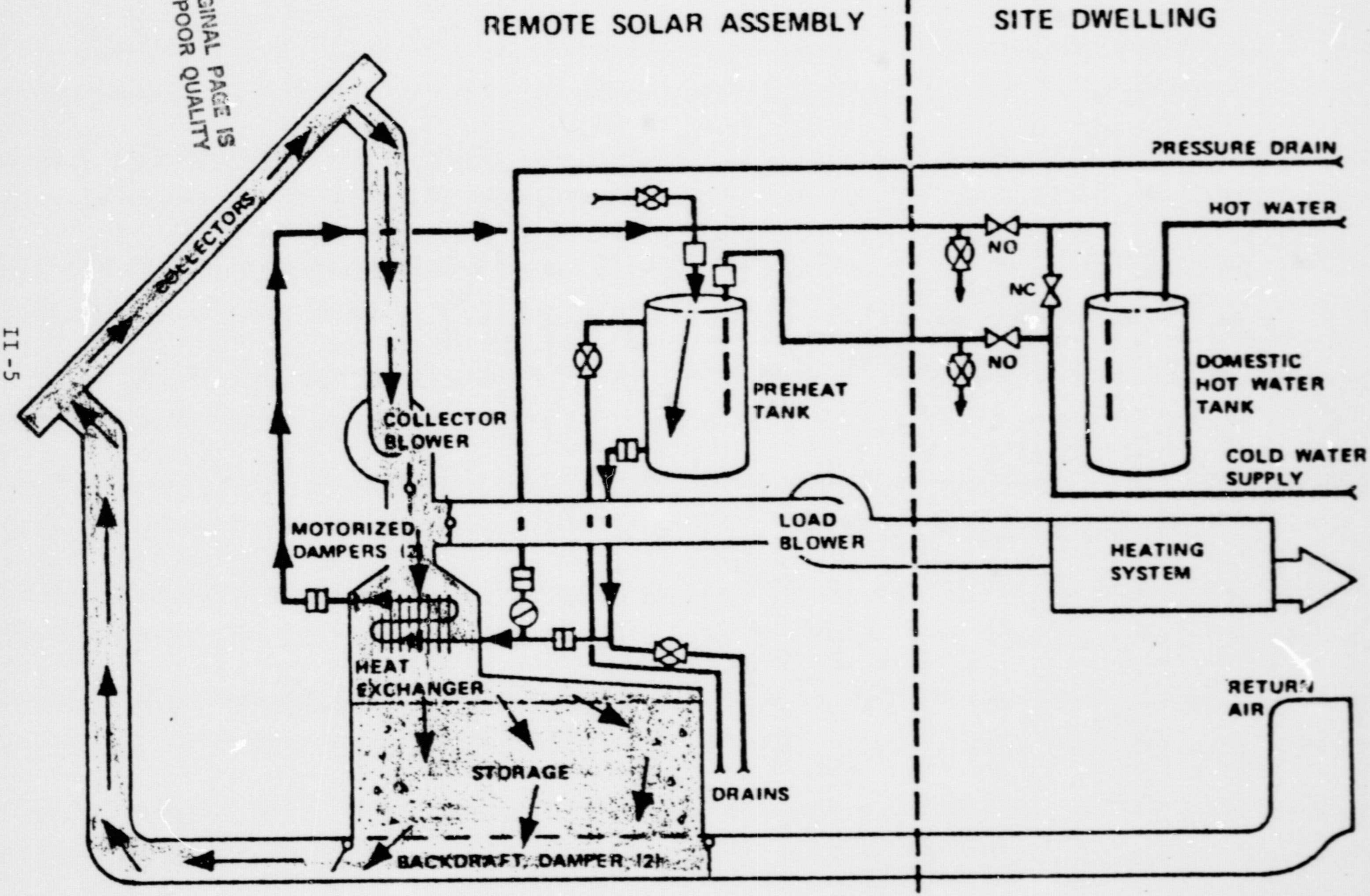
3.1 Basic Solar Heating System #4

The basic solar heating system #4 is the DOE/NASA SIMS prototype solar heating system #4 (MSFC System #4) as referenced in MFS-23924, 25022, 25116 and 823924 reports.

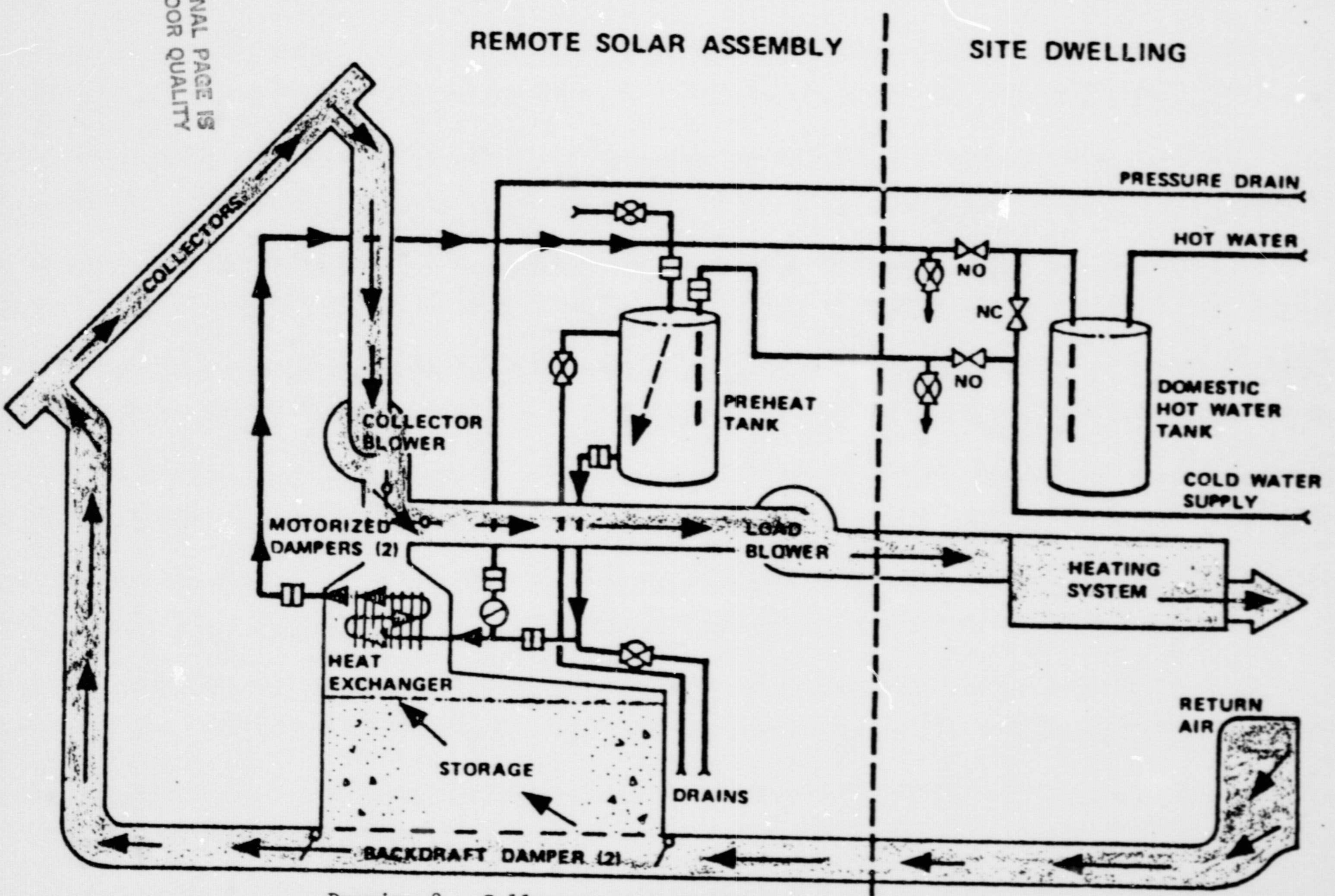
The basic system #4 operates in three separate and distinct modes as indicated on drawings 1, 2 and 3.

The cost study is divided into three separate categories based on the total number of units manufactured, and the final installation costs.

- Cost study #1 is based on producing one single unit to be installed in the Chicago Metropolitan area
- Cost study #2 is based on mass producing 10,000 systems (yearly production), and distributing to localized dealers for their sale to the final user.
- Cost study #3 is the final fixed installation and site improvement costs required to deliver, set up, connect and start-up a single system in the Chicago Metropolitan area. This cost should remain constant even if the system is mass produced.



Drawing 1. Collector-to-Storage Mode



Drawing 2. Collector-to-Load Mode

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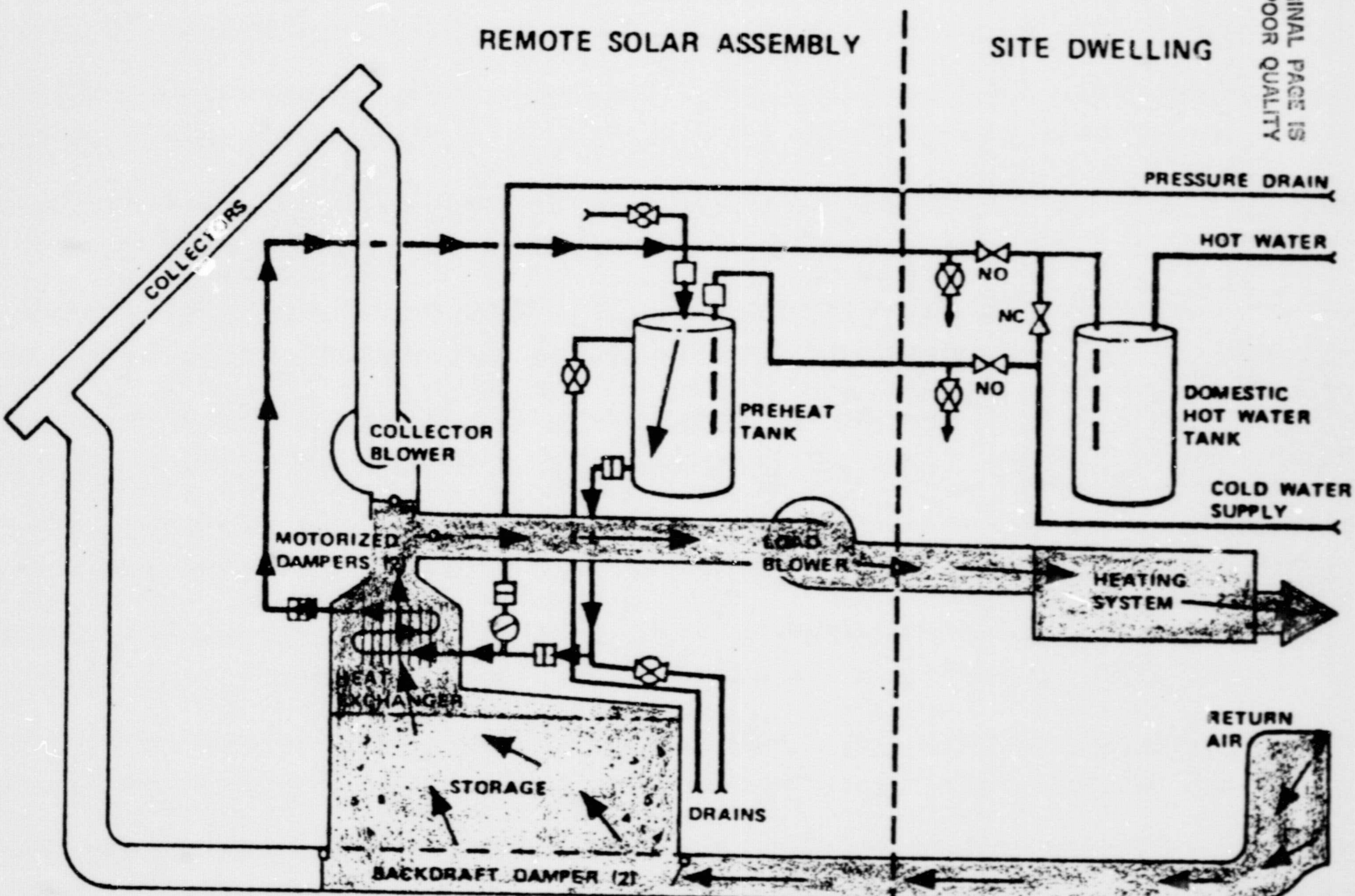

Drawing 3. Storage-to-Load Mode

4. Cost Study #1 - (One Unit)

4.1 Cost Study #1 - Recap

Major Components	$ 5,582.36
Control Devices	439.39
Piping Materials	394.74
Wiring Materials	100.16
Ducting Materials	250.15
Rock Storage Bin Materials	764.74
Insulation Materials	1,469.11
Misc. Materials	66.20
Labor - Mechanical	3,833.50
Housing Materials	10,748.41
Labor - Housing	4,368.00
Warranty Provision	214.57
Contractors Overhead	4,234.70
Contractors Profit	3,246.60
Total Cost	$35,712.63

4.2 Cost Study #1 - Single Unit

Major Components

12 Collectors @ $420.00 ea.	$ 5,040.00
1 Blower - Collector Loop	120.08
1 Blower - Load Loop	122.28
1 Coil	120.00
1 Water Tank, 66 Gal.	180.00
Total Major Components	$ 5,582.36

Control Devices

2 Controllers @ 81.23 ea.	$ 162.46
4 Sensors @ $11.25 ea.	45.00
1 Well	5.00
1 Storage Temp., High Limit	30.69
1 Storage Temp., Low Limit	30.69
1 Preheat, High Limit	6.54
2 Relays	24.60
1 Thermostat	41.67
1 Switch	2.10
1 Legend Plate	2.50
2 Control Transformers	8.69
2 Damper Motors	79.45
Total Control Devices	$ 439.39

Piping Materials

Copper Pipe, Valves & Fittings	$ 82.69
C.P.V.C. Pipe, Valves & Fittings	103.96
Piping Supplies	37.33
Temp-Press Relief Valve	5.00
Thermal Bleeder Valve	165.76
Total Piping Materials	$ 394.74

Wiring Materials

125'	Greenfield	$ 19.01
30'	Conduit	3.62
70'	Wire #14 THW	2.90
300'	Wire #12 THW	18.06
	Shielded Cable	10.00
	Misc. Supplies	10.72
1	Recepticle	1.30
1	Panel Board	7.25
4	Circuit Breakers	12.00
1	Fluorescent Fixture	11.50
1	Switch	1.79
1	Fluorescent Tube	2.01
	Total Wiring Materials	$ 100.16

Ducting Materials

2	Control Dampers @ $24.57 ea.	$ 49.14
2	Back Draft Dampers @ $15.00 ea.	30.00
2	Balancing Dampers @ $ 1.50 ea.	3.00
	Ductwork (Round)	55.31
	Ductwork (Rectangular)	58.37
	Misc. Supplies	44.33
	Aluminum	10.00
	Total Ducting Materials	$ 250.15

Rock Storage Bin Materials

Grating	$ 119.44
Wire	13.51
Perforated Metal	8.00
Structural Angles	23.04
Misc.	8.91
Panels	511.36
Adhesive	20.00
Corner Strips	60.48
Total Rock Storage Bin Materials	$ 764.74

Insulation Materials

Urethane Materials	$ 795.00
285 S.F. Duct Covering	656.81
34 L.F. Armaflex	14.42
Misc. Supplies	2.88
Total Insulation Materials	$1,469.11

Misc. Materials

Storage Racks	$ 50.00
1 V Belt	1.43
1 Motor Pulley	6.18
1 Blower Pulley	8.59
Total Misc. Materials	$ 66.20

Labor - Mechanical

Set Collectors	16 Man Hours	
Set Blower	2 Man Hours	
Set Blower	2 Man Hours	
Set Coil	3 Man Hours	
Set Hot Water Tank	2 Man Hours	
Fabricate Rock Storage Bin	28 Man Hours	
Set Controls	6 Man Hours	
Set Rock Storage Bin	4 Man Hours	
Piping	14 Man Hours	
Ductwork	28 Man Hours	
Wiring	16 Man Hours	
Test Controls	4 Man Hours	
Paint	3 Man Hours	
Install Control Dampers	3 Man Hours	
Install Back Draft Dampers	2 Man Hours	
Install Balancing Damper	1 Man Hour	
Shop Handling	8 Man Hours	
Insulation	37 Man Hours	
Misc.	4 Man Hours	
Belt Guards	4 Man Hours	
Total Man Hours	187 Man Hours	
Total Man Hours @ $20.50 per Man Hour		$3,833.50

Housing Materials

650 L.F. 4" Aluminum Channel @ $6.53	$ 4,244.50
164 L.F. 6" Aluminum Channel @ $10.61	1,740.04
20 L.F. 8" Aluminum Channel @ $15.56	311.20
68 L.F. 12" Aluminum Channel @ $31.01	2,108.68
200 Aluminum Clip Angles	900.00
1200 Rivets & Screws	150.00
377 S.F. Aluminum Siding @ 75¢	282.75
48 S.F. Fiberglass Roof Panels @ $5.00	240.00
Roof Panel Trim	75.00
76 L.F. 2" Aluminum "T" Mouldings @ $4.24	322.24
Misc. Fittings	100.00
Roof Top Ventilator	65.00
1 Entry Door w/Hardware	184.00
Paint & Stain	25.00
Total Housing Materials	$10,748.41

Labor - Housing

Erect Exterior Framing	32 Man Hours	
Erect Roof Framing	16 Man Hours	
Install Cross Ties, Intermediate Framing & Ridge Channel	114 Man Hours	
Install Aluminum Siding	10 Man Hours	
Install Fiberglass Roof Panels & Trim Solar Panels	26 Man Hours	
Install Misc. Fittings & Roof Ventilator	15 Man Hours	
Install Entry Door	8 Man Hours	
Paint & Stain	3 Man Hours	
Total Man Hours	224 Man Hours	
Total Man Hours @ $19.50 per Man Hour		$ 4,368.00

Contractors overhead consists of office expenses, estimators salaries, insurance, auto and truck expenses and depreciation, equipment maintenance and utilities. We have used a general figure of 15% of the total job costs.

Contractors profit is estimated at 10% of the total project costs.

5. Cost Study #2 - (10,000 Units)

5.1 Cost Study #2 - Recap

Major Components	$ 3,516.70
Control Devices	328.19
Piping Materials	243.71
Wiring Materials	84.16
Ducting Materials	207.57
Rock Storage Bin Materials	653.26
Insulation Materials	965.30
Misc. Materials	49.40
Labor. - Mechanical	1,012.73
Housing Materials	3,960.57
Labor - Housing	676.80
Manufacturing Experience (overhead)	3,379.06
Manufacturers Profit	603.10
Total Cost	$15,680.55

5.2 Cost Study #2 - 10,000 Units

Major Components

12 Collectors @ $262.00 ea	$ 3,081.12
1 Blower - Collector Loop	88.23
1 Blower - Load Loop	89.85
1 Coil	97.50
1 Water Tank, 66 Gal.	160.00
Total Major Components	$ 3,516.70

Control Devices

2 Controllers @ $60.92 ea.	$ 121.85
4 Sensors @ $8.43	33.75
1 Well	3.75
1 Storage Temp., High Limit	23.02
1 Storage Temp., Low Limit	23.02
1 Preheat, High Limit	4.81
2 Relays @ $9.22 ea.	18.45
1 Thermostat	31.25
1 Switch	1.68
1 Legend Plate	.50
2 Transformers @ $3.26 ea.	6.52
2 Damper Motors @ $29.79 ea.	59.59
Total Control Devices	$ 328.19

Piping Materials

Copper Pipe, Valves & Fittings	$ 63.57
C.P.V.C. Pipe, Valves & Fittings	69.31
Piping Supplies	26.58
Temp-Press Relief Valve	4.25
Thermal Bleeder Valve	80.00
Total Piping Materials	$ 243.71

Wiring Materials

125'	Greenfield	$ 16.16
50'	Conduit	3.25
70'	Wire #14 THW	2.32
300'	Wire $12 THW	14.69
	Shielded Cable	8.00
	Misc. Supplies	8.88
1	Recepticle	1.11
1	Panel Board	6.16
4	Circuit Breakers	10.20
1	Fluorescent Fixture	10.35
1	Switch	1.43
1	Fluorescent Tube	1.61
	Total Wiring Materials	$ 84.16

Ducting Materials

2	Control Dampers @ $15.50 ea.	$ 31.00
2	Back Draft Dampers @ $10.00 ea.	20.00
2	Back Balancing Dampers @ $1.00 ea.	2.00
	Ductwork (Round)	44.24
	Ductwork (Rectangular)	58.37
	Misc. Supplies	41.96
	Aluminum	10.00
	Total Ducting Materials	$ 207.57

Rock Storage Bin Materials

Grating	$ 107.49
Wire	10.81
Perforated Metal	4.88
Structural Angles	10.98
Misc.	4.96
Panels	449.11
Adhesive	45.03
Corner Strips	20.00
Total Rock Storage Bin Materials	$ 653.26

Insulation Materials

Urethane Materials	$ 426.00
285 S.F. Duct Covering	525.45
34 L.F. Armaflex	11.54
Misc. Supplies	2.31
Total Insulation Materials	$ 965.30

Misc. Materials

Storage Rocks	$ 36.50
1 V Belt	1.05
1 Motor Pulley	4.54
1 Blower Pulley	6.31
Total Misc. Materials	$ 49.40

Labor - Mechanical

Set Collectors	16 Man Hours	
Set Blower	2 Man Hours	
Set Blower	2 Man Hours	
Set Coil	3 Man Hours	
Set Hot Water Tank	2 Man Hours	
Fabricate Rock Storage Bin	26 Man Hours	
Pipeline	14 Man Hours	
Ductwork	25 Man Hours	
Test Controls	2 Man Hours	
Paint	2 Man Hours	
Install Control Dampers	3 Man Hours	
Install Back Draft Dampers	2 Man Hours	
Install Balancing Dampers	1 Man Hours	
Shop Handling	8 Man Hours	
Insulation	37 Man Hours	
Misc.	4 Man Hours	
Belt Guards	4 Man Hours	
Total Man Hours	169 Man Hours	
Total Man Hours @ $7.05 per Man Hour		$ 1,012.73

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Housing Materials

650 L.F. 4" Aluminum Channel @ $1.93	$ 1,254.50
164 L.F. 6" Aluminum Channel @ $3.13	513.32
20 L.F. 8" Aluminum Channel @ $4.59	91.80
68 L.F. 12" Aluminum Channel @ $9.15	622.20
200 Aluminum Clip Angles	540.00
1200 Rivets & Screws	90.00
377 S.F. Aluminum Siding	212.00
48 S.F. Fiberglass Roof Panels	180.00
Roof Panel Trim	50.00
76 L.F. 2" Aluminum "T" Mouldings @ $1.25	95.00
Misc. Fittings	75.00
Roof Top Ventilator	57.50
1 Entry Door w/Hardware	166.75
Paint & Stain	12.50
Total Housing Materials	$ 3,960.57

Labor - Housing

Erect Exterior Framing	16 Man Hours	
Erect Roof Framing	8 Man Hours	
Install Cross Ties, Intermediate Framing & Ridge Channel	32 Man Hours	
Install Aluminum Siding	6 Man Hours	
Install Fiberglass Roof Panels & Trim Solar Panels	14 Man Hours	
Install Misc. Fittings and Roof Ventilator	8 Man Hours	
Install Entry Door	3 Man Hours	
Paint & Stain	1 Man Hours	
Shop Handling	8 Man Hours	
Total Man Hours	96 Man Hours	
Total Man Hours @ $7.05 per Man Hour		$ 676.80

Manufacturing experience consists of insurance, benefits, plant burden and general administration. We have used the accepted formula of twice the direct labor costs.

Profit has been estimated at 4% of the total manufactured cost.

6. Cost Study #3 - (Site Costs)

6.1 Cost Study #3 - Recap

Excavation	$ 570.00
Concrete	1,736.75
Final Connections	500.00
Total Cost	$2,806.75

Excavation

Trench Wall 18 C.Y. @ $5.00	$ 90.00
Backfill	
Exterior Clay - 8 C.Y. @ $5.00	40.00
Interior - Sand - 20 C.Y. @ $8.00	160.00
Haul Spoil - 10 C.Y. @ $10.00	100.00
Misc. Grading - 1 hr. @ $60.00	60.00
Overhead, 15%	75.00
Profit, 10%	50.00
Total Excavating Cost	$ 570.00

Concrete

Footings - 5 C.Y. @ $120.00	$ 600.00
Walls - 4.5 C.Y. @ $120.00	540.00
Slab - 243 S.F. @ $2.25	546.75
Misc. Disposable Items	50.00
Total Concrete Cost	$1,736.75

Final connections to the existing system are an unknown item. We have used an allowance of $500.00 to connect ductwork, piping, and make electrical connections.

7. Conclusions and Recommendations

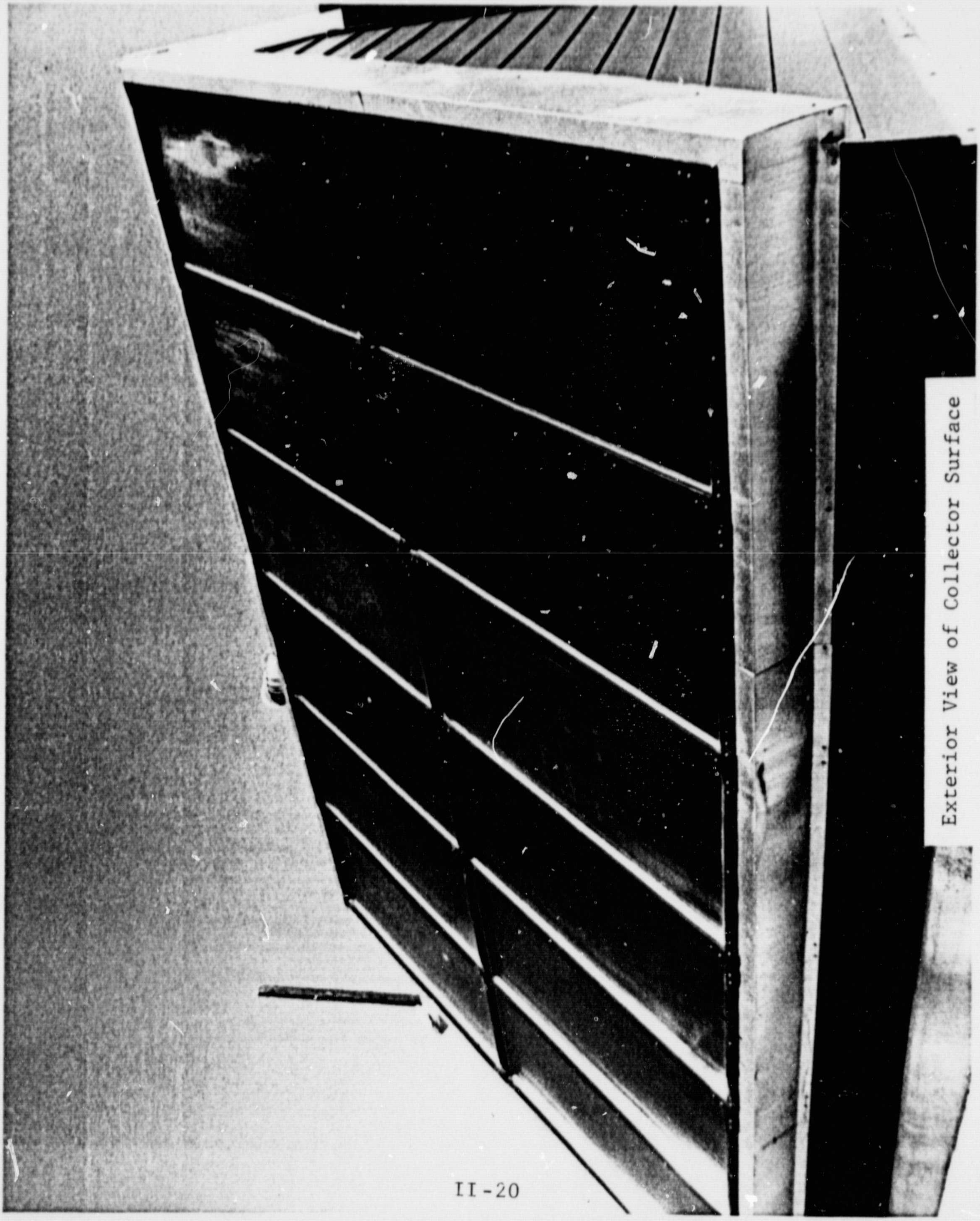
7.1 Conclusions

The system is housed in a semi-portable building which challenges local building codes, zoning requirements, and architectural standards of many residential Metropolitan Chicago areas. These factors influence the accuracy of the cost estimate.

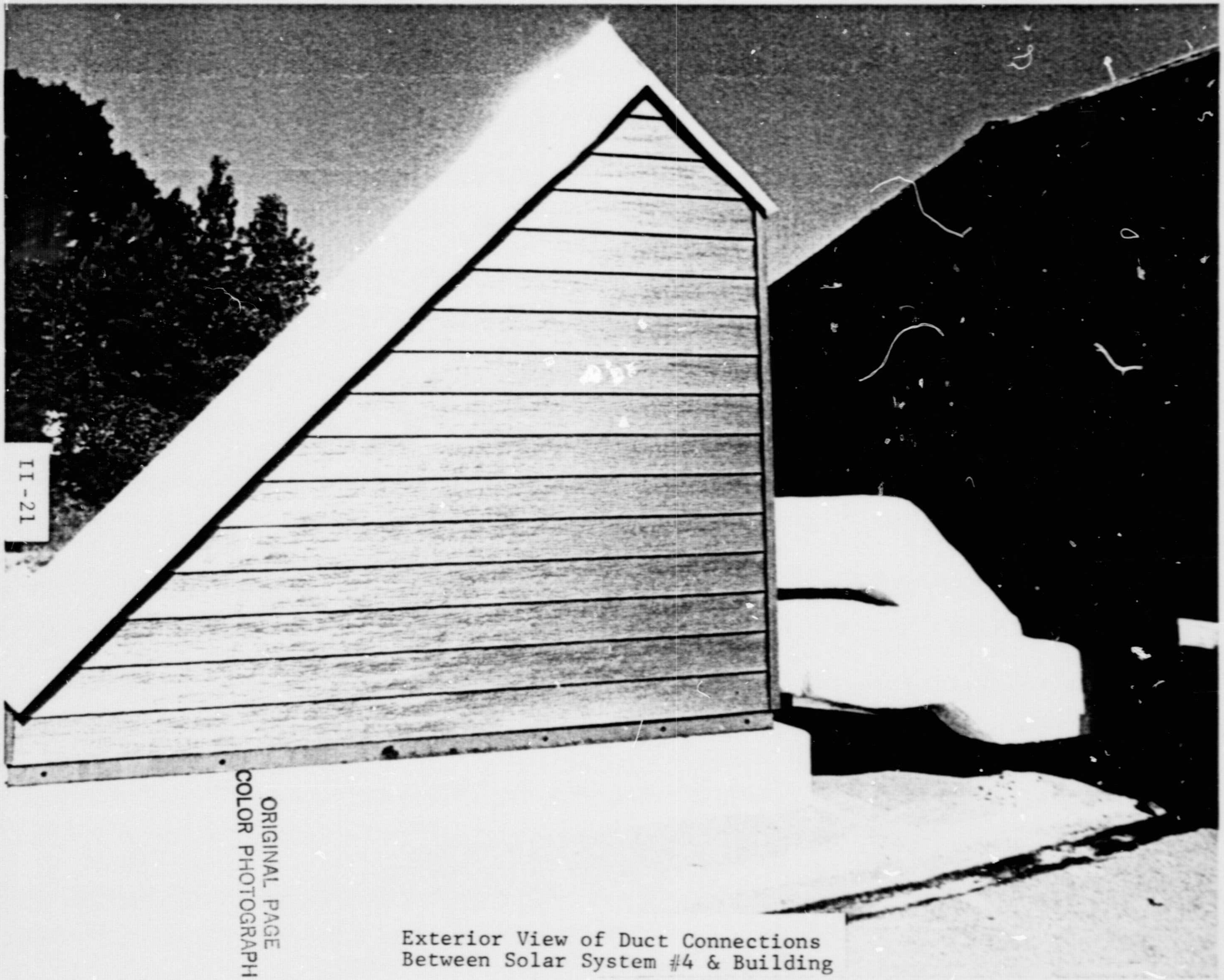
- The system, as designed, will not meet the City of Chicago building code requirements.
- The conditions and restrictions that the systems must meet eliminate it from the new and remodeling market in the Chicago Metropolitan area.
- The system as installed at the Jackson, Mississippi facility will not meet Chicago building codes.
- The total cost to manufacture and install system #4 as designed in the Greater Chicago area is estimated at $38,518.00. The cost in quantities of 10,000 will be $18,486.00.
- The use of aluminum extruded structural members has a significant impact on the cost of building materials required for the system.
- Modifications in building materials selection and design may make it possible to manufacture and install the system for less than $5,000.00.
- Blowers and dampers specified are sub-standard for the residential application intended.
- The thermal bleed valve specified will not operate effectively in the Chicago area since water temperatures can be close to freezing.

7.2 Recommendations

- It is recommended that a second cost estimate be performed to determine the lowest cost in which the system can be manufactured when incorporating design and materials changes. The design and materials changes will enable conformance to building code requirements.
- Perform a System #4 cost estimate for a commercial/industrial building application, since code requirements will be easier to conform to.
- Perform a cost estimate utilizing the system as a portable heating source in agricultural applications.



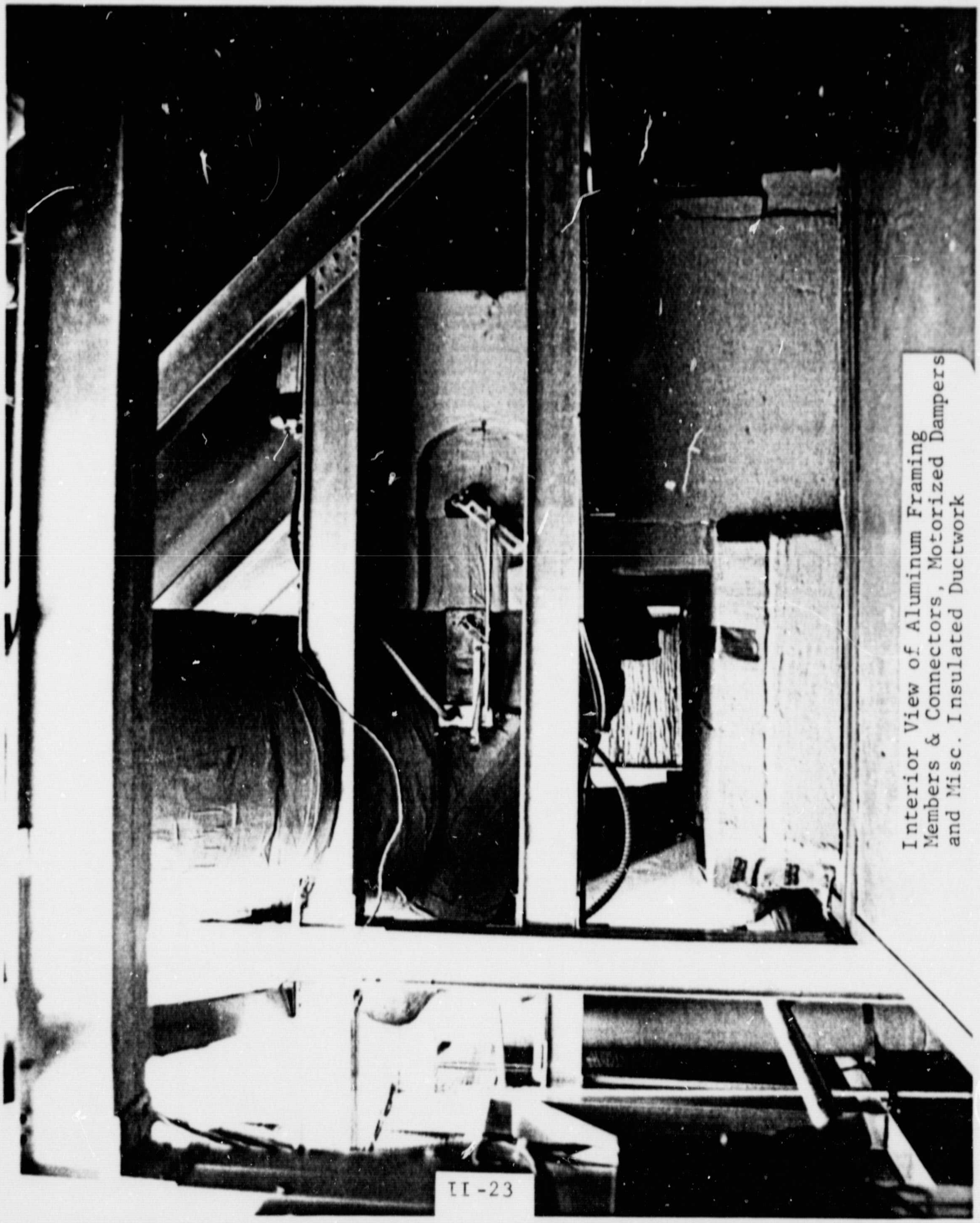
Exterior View of Collector Surface



Exterior View of Duct Connections
Between Solar System #4 & Building

ORIGINAL PAGE
COLOR PHOTOGRAPH

Exterior View of Relationship of Collectors, Duct Connections & Building



Interior View of Aluminum Framing Members & Connectors, Motorized Dampers and Misc. Insulated Ductwork